Technical Report **R 738**

INVESTIGATION OF EMPTY WOODEN AMMUNITION BOXES FOR PROTECTIVE CONSTRUCTION

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by

J. M. Ferritto

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Empty ammunition boxes can serve as elements for construction of beams and bunkers to protect troops in the field. Various beam load tests have shown that it is possible to construct beams capable of safely carrying 2 feet of soil. Two specific designs are presented for beams which can span 7 and 10 feet carrying 2 feet of soil with a safety factor of 2. The problem of wood deterioration and loss of beam strength has been investigated and found not to be very significant. Beams placed side by side can serve as foxhole covers. Soil stability data are presented to determine minimum bearing areas required. Bunker construction plans have been developed and evaluated. Tests show the bunkers can be fabricated and will safely support the overhead load produced by 2 feet of soil protection. Blast and fragmentation tests indicate that the amount of protection given by a bunker is adequate against a 155-mm artillery round.

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Empty ammunition boxes can serve as elements for construction of beams and bunkers to protect troops in the field. Various beam load tests have shown that it is possible to construct beams capable of safely carrying 2 feet of soil. Two specific designs are presented for beams which can span 7 and 10 feet carrying 2 feet of soil with a safety factor of 2. The problem of wood deterioration and loss of beam strength has been investigated and found not to be very significant. Beams placed side by side can serve as foxhole covers. Soil stability data are presented to determine minimum bearing areas required. Bunker construction plans have been developed and evaluated. Tests show the bunkers can be fabricated and will safely support the overhead load produced by 2 feet of soil protection. Blast and fragmentation tests indicate that the amount of protection given by a bunker is adequate against a 155-mm artillery round.

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CONTENTS

INTRODUCTION

Objective

This work is intended to provide specific guidance to combat Marine units on the use of empty wooden ammunition boxes in protective construction. Methods will be given for fabricating building elements from empty ammunition boxes for the construction of bunkers to obtain protection from hostile fire. The specific areas of this study included:

1. Developing and evaluating structural beams fabricated from boxes
2. Evaluating wood deterioration
3. Developing and evaluating plans for bunker construction
4. Evaluating the protection afforded by soil-filled boxes subjected to various ordnance detonations

Background

The Naval Civil Engineering Laboratory (NCEL) has been requested to provide guidance to the Marine Corps on the utilization of wooden ammunition boxes as basic construction elements. The wooden box in a beam configuration represents an application which can satisfy many of the needs for protection of a Marine in the field. Under present doctrine, the basic Marine infantry unit deployed in combat is initially limited to local natural building materials. For building implements, the individual Marine has only an intrenching tool and a bayonet. Thus, field construction must be very simple, requiring few tools and materials.

The infantry battalion, the basic tactical unit of ground combat power, is a balanced firepower and maneuver team. It is usually assigned an area of responsibility in which it operates to attack and destroy specified targets. The infantry battalion consists of a headquarters and services company and four rifle companies. The rifle companies are the basic tactical units with which the battalion accomplishes its mission. The basic mobility is by foot

supplemented by small, lightweight vehicles for transportation of equipment, weapons, and supplies. Within the battalion are a 106-mm recoilless rifle platoon and an 81-mm mortar platoon. The recoilless rifle platoon has eight 106-mm recoilless rifles, which fire about 20 rounds per day per weapon in a normal attack support position.[1] The mortar platoon has eight 81-mm mortars, which fire about 75 rounds per day per weapon in a normal attack support position.[1] The 106-mm rounds are packed two each in a wooden box 45-1/2 by 13 by 8 inches, and the 81-mm rounds are packed three each in a box 27 by 14 by 6 inches. Thus, an average day's firing by a battalion provides 80 empty 106-mm recoilless rifle ammunition boxes and 200 empty 81-mm mortar ammunition boxes. Fifteen days' supply is usually maintained in a mobile field operation. Additionally, each rifle company has a weapons platoon with three 60-mm mortars and six 3.5-inch rocket launchers. The required mobility of these units, however, precludes full utilization of the boxes in temporary construction. In several days' firing, it is evident that large quantities of empty boxes are generated.

Providing protection for the Marine is of prime importance. Protection should be provided against all probable hazards except direct hits for a range of weapons up to and including 152-mm cannon. The frequent use of 122-mm rockets by the North Vietnamese warrants specific attention; protection of at least 24 inches of soil is required to provide a satisfactory bunker.[2,3] The bunker must be strong, simple, and capable of construction with the tools and materials immediately available.

Soil-filled wooden ammunition boxes are presently being substituted for sandbags. In moist tropical climates, sandbags deteriorate very rapidly and require large expenditures of man-hours to maintain protection. The wooden box filled with soil is currently an element in bunker wall construction. This can be extended to overhead protection if the boxes can be joined together to form a beam element. This will be discussed at greater length in following sections of this report.

The boxes can also be used with issued materials to upgrade field living quarters. An example of this is combining a standard tent with walls and a floor of boxes.[4,5]

Problems do exist in construction with ammunition boxes. Many times firing occurs at dispersed locations, resulting in the empty boxes having to be transported to a central area for accumulation. Protection is required even before firing begins, and before empty boxes are available in large quantities. In many instances, ammunition is broken out of the boxes in rear areas to reduce weight for shipment to the front lines. The boxes are made from scrap lumber of poor quality. Experience has shown that the boxes may deteriorate in a few months, especially when placed in contact with wet ground.

It is not intended for the ammunition box bunker to replace any existing or proposed protection method. The approach taken in this research effort is that if empty ammunition boxes are available in sufficient quantities, the Marine in the field should be given specific instruction to obtain the maximum protection from them. Improper, unsafe construction by untrained personnel utilizing empty ammunition boxes could result in a larger number of casualties if a bunker collapses under load than if no protection were used.

CONSTRUCTION METHODS AND PROCEDURES

Definition of Threat

Personnel protection is required from the effects of blast and fragmentation from a near miss from conventional indirect-fire infantry weapons known to be available to the enemy. Because indirect-fire weapons are aimed at area targets rather than at point targets, direct hits on bunkers should not occur frequently. Therefore, the major emphasis for this study has been on near misses.

The following types and calibers of weapons have been identified as being available to the enemy in the Republic of Vietnam and are suitable for indirect-fire attack.[6]

Soviet	Chinese Communist
82-mm mortar	60-mm mortar
102-mm rocket	81-mm mortar
107-mm rocket	82-mm mortar
120-mm rocket	
122-mm rocket	
130-mm rocket	
140-mm rocket	
152-mm cannon	

Of these, the largest frequently occurring weapon is the 122-mm rocket. The casing of this rocket is specially machined to produce a large number of fragments of lethal size. Calculations using the Poncelet equation of fragment-velocity attenuation applied to the largest 122-mm rocket fragment from a close detonation indicate that two ammunition boxes filled with sand (24 inches of sand and 3 inches of wood) are sufficient to stop all lethal

fragments. Based on this criterion, a ***minimum*** thickness of 2 feet of soil is required in all bunkers. Evaluation of this criterion is discussed later in this report.

Overhead Beam Construction

Numerous methods of joining ammunition boxes together to produce structural beams, using various additional materials and tools were tried. Details of these tests are presented in Appendixes A and B. Since it was not possible to test all the different types of boxes in the government inventory, boxes for 81-mm and 106-mm ammunition were selected because they are used in large quantities and represent the upper and lower size limits of most ammunition boxes.

Several types of the beams tested were found satisfactory. However, to simplify construction procedures, one type of beam was selected and is recommended for use. This beam is simple to construct and requires only nails and a hammer. The beam construction procedure consists of disassembling several boxes and using the sides, lids, and bottoms to join other boxes together. Figures 1 and 2 show the construction of a beam with 81-mm ammunition boxes. These beams are four boxes long and can, placed side by side, safely span 7 feet supporting 2 feet of soil (Beam 8, Appendix A). Figures 3 and 4 show the construction of a beam with 106-mm ammunition boxes. These beams are three boxes long and can, placed side by side, safely span 10 feet supporting 2 feet of soil (Beam 1, Appendix B).

The boxes are not filled with soil, since this would make them very heavy to lift; rather, soil is placed on top of the beams. Figure 5 illustrates that beams constructed under field conditions with 106-mm ammunition boxes by Marines not trained in this work can support 4 feet of soil. Since these beams are intended to support 2 feet of soil, under normal conditions there is a factor of safety of at least 2.0. During a rainstorm, moisture will be absorbed by the soil placed over the beams, increasing the loading on the beams. For sand materials the increase in weight would probably not exceed 15%; however, for clay materials the increase in weight may be as much as 50%. This would reduce the factor of safety to about 1.33. The permeability of clay is very low, and the material tends to seal itself so that only the outer layer becomes saturated. To maintain a high factor of safety, the soil should be covered with plastic and sloped to drain rapidly. Actual tests conducted on soil bags filled with native Port Hueneme clay indicate an increase in weight of 32% from dry to fully saturated conditions. This would correspond to a reduction in factor of safety from 2.0 to 1.5.

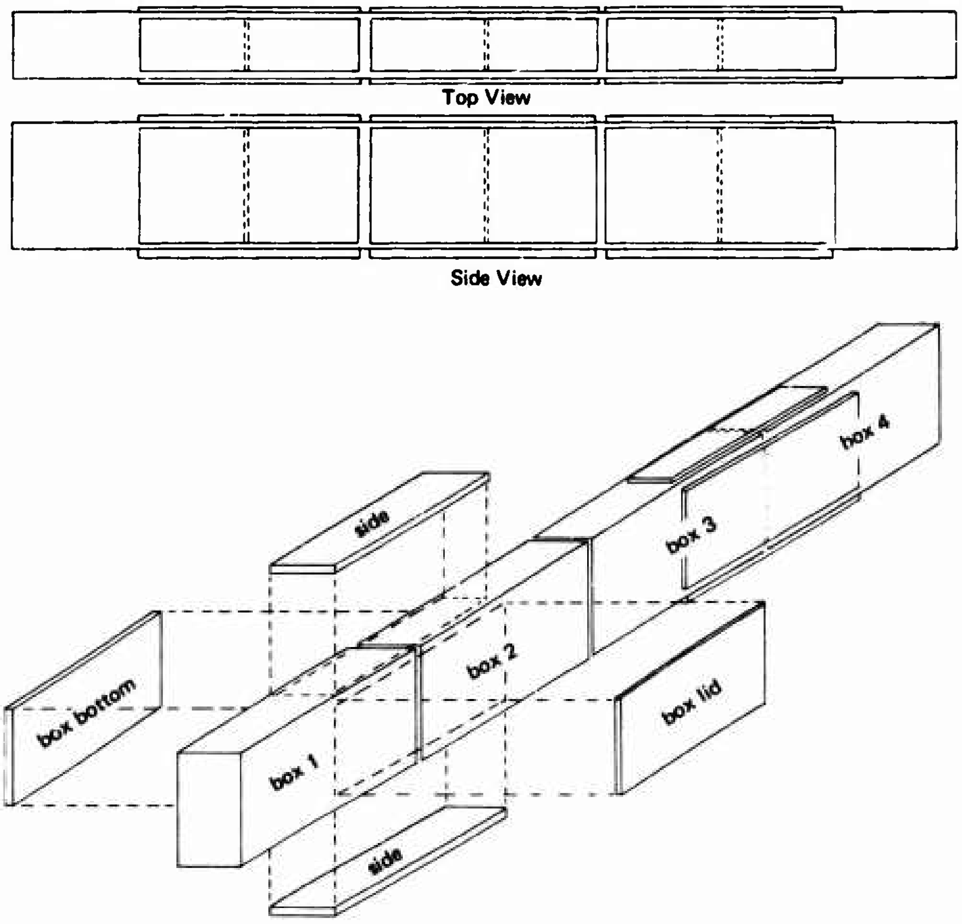


Figure 1. Construction plan for beam made from four 81-mm ammunition boxes (7-foot clear span).

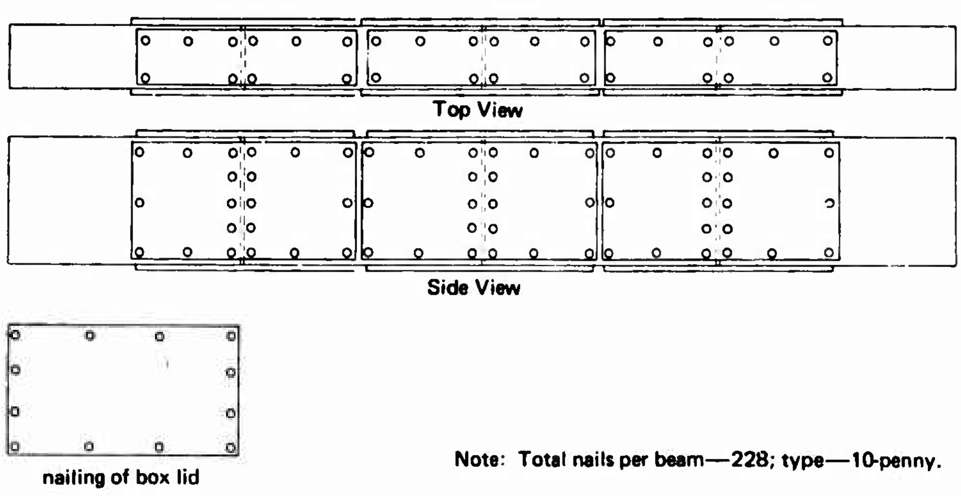


Figure 2. Nail pattern for beam made from four 81-mm ammunition boxes.

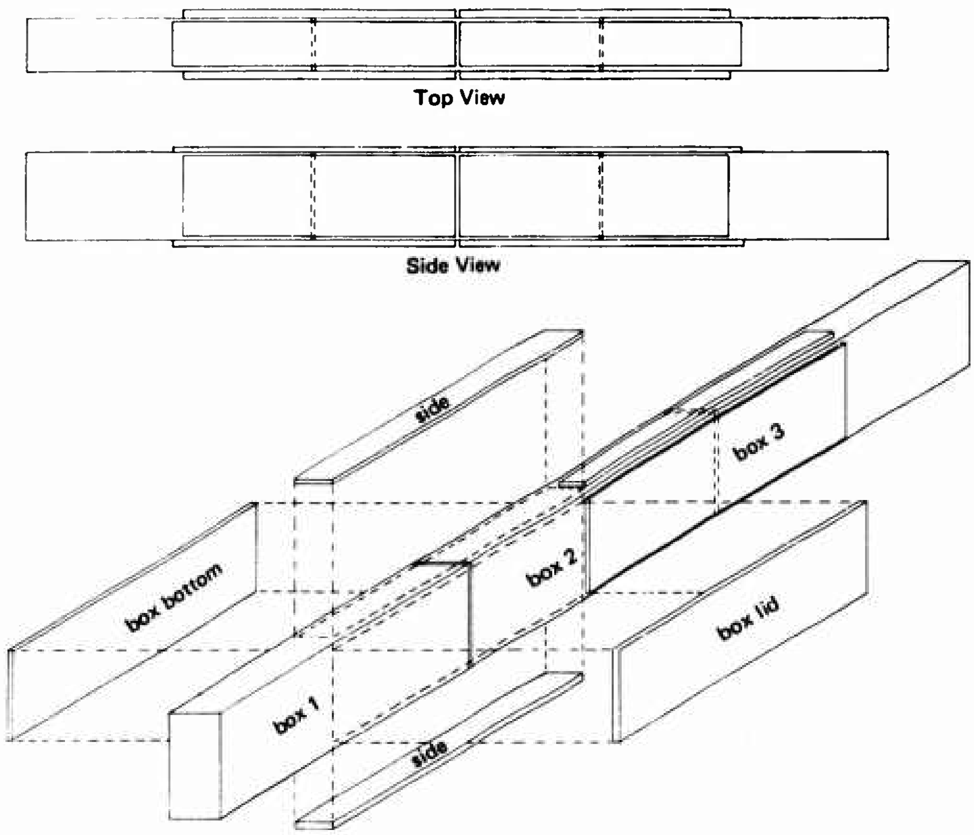
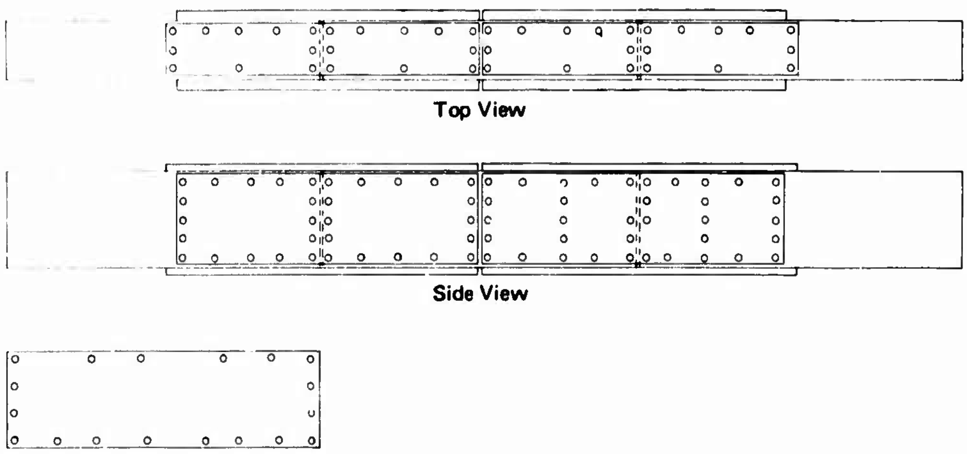


Figure 3. Construction plan for beam made from three 106-mm ammunition boxes (10-foot clear span).



Note: Total nails per beam—262; type—10-penny.

Figure 4. Nail pattern for beam made from three 106-mm ammunition boxes.

Figure 5. Field load test of beams.

Wood Deterioration Tests

Tests have been conducted evaluating the extent of deterioration of treated and untreated wooden beams on exposure to the environment (Appendix C). These tests indicate there is no significant loss of strength of the wooden beams for several months. Treated and untreated beams behaved similarly. It is only after 6 months that untreated wooden beams begin to show loss of strength. However, this period of time would probably exceed the requirements of temporary bunker construction. Consequently, little is gained by treating boxes with a wood preservative.

Foxhole Covers

As mentioned previously, protection may be required before large quantities of boxes become available. A temporary expedient is to place box beams side by side as a cover over a foxhole dug in the ground. Figure 6 shows a sketch of this concept. The beams must have a sufficient bearing area on the

soil to prevent failure of the sloped sides. The amount of bearing area required depends on the type of soil. Appendix D contains data to determine the minimum length of beam (ΔL) to provide bearing on soil of various types.

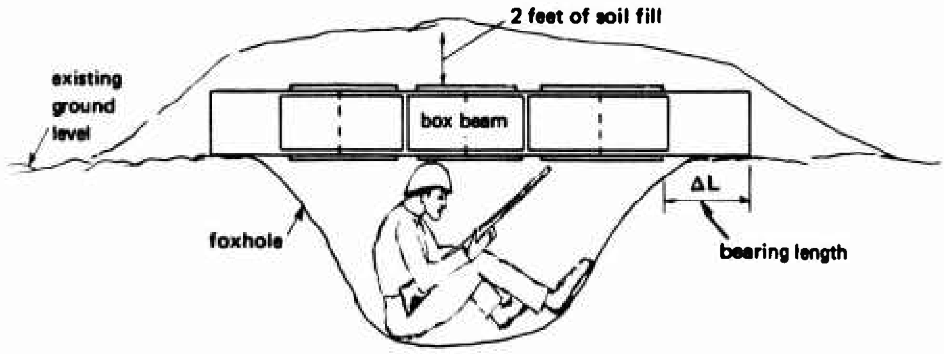


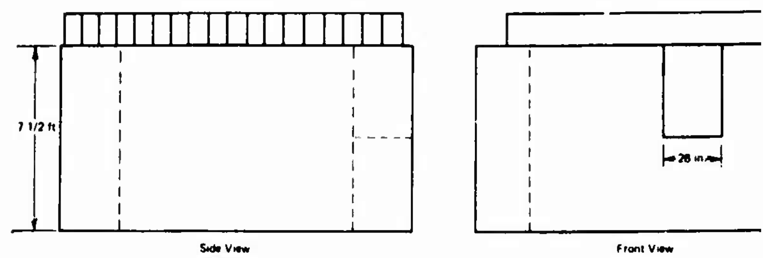
Figure 6. Foxhole cover made with box beams.

Bunker Construction Plans

Figure 7 shows the construction of a bunker with 106-mm ammunition boxes. Figure 8 shows the construction of a bunker with 81-mm ammunition boxes. Where terrain permits, half of the bunker should be below grade. A properly sized hole should be dug and the ground leveled for placement of the bottom layer of boxes forming the wall. The boxes should be filled with soil, nailed closed, and placed in position. To prevent fragments from entering in the bunker between boxes, the wooden cleats on the box lids *must* be removed. The cleat can most easily be removed with the claw of a hammer after the box is filled with soil, nailed closed, and placed in position. The layers of boxes should be staggered as shown in Figures 7 and 8 to avoid lines of weakness. After all the layers of boxes are in position and the walls are complete, the overhead beams are placed on the supporting walls. The tops of beams should be nailed together with box lids to form a deck to prevent lateral movement. Boxes filled with soil or sandbags should be placed around the sides and at the ends of the beams to protect them from fragments. Two feet of soil, either in boxes or sandbags, should be placed on top of the beams. Figure 9 shows a completed bunker built with 106-mm ammunition boxes. This bunker has about 100 square feet of usable space and was built in 160 man-hours, not including the excavation of the hole. Appendix E gives additional data and photographs of the construction and evaluation of this bunker.

A

B



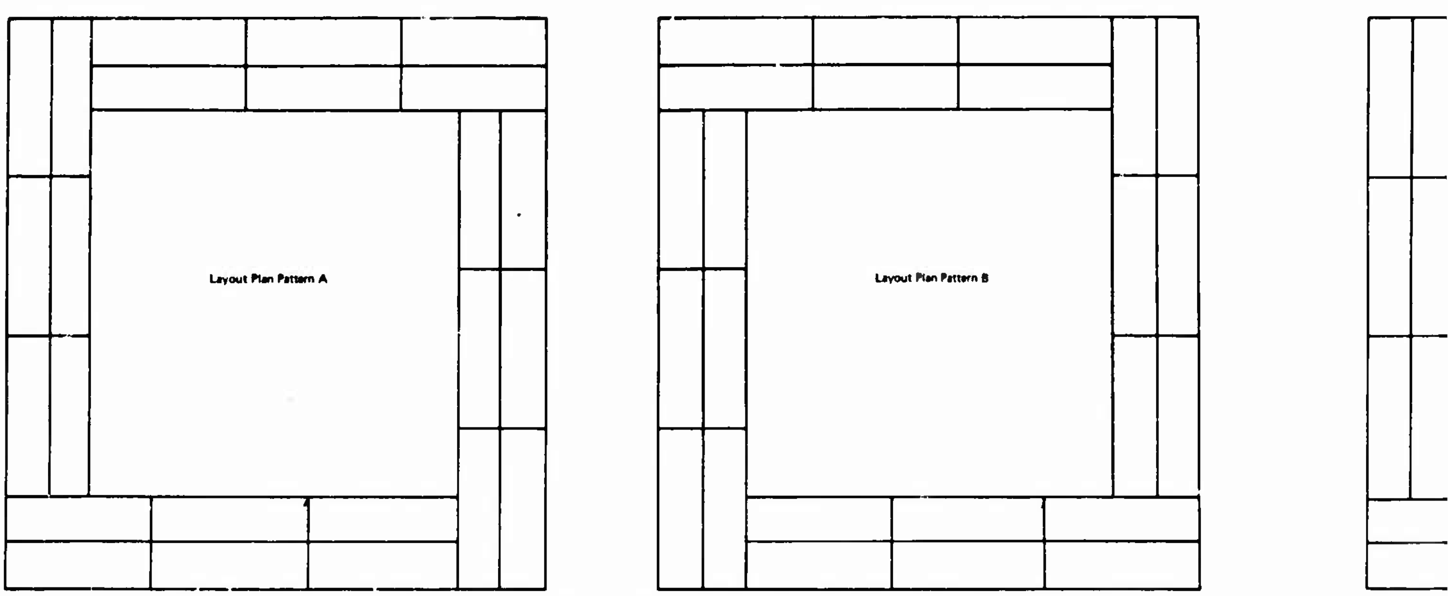
Steps

1. Excavate hole to depth of about 3 1/2 feet and level ground for bottom row of boxes
2. Construct overhead beams (minimum 18 required). See beam plans, Figures 3 and 4
3. Fill boxes with soil. Nail lids closed. Remove cleats
4. Stack boxes in staggered pattern to avoid areas of weakness. Nail as required. See layout patterns

Layer	Pattern
1	A (bottom)
2	B
3	A
4	B
5	A
6	B
7	C
8	D
9	C
10	D
11	C
12	D

5. Place beams in position. Nail together as required with lids from other boxes
6. Fill and place sandbags on top of beams to provide 2 feet of soil protection

(a) Side, front, and section

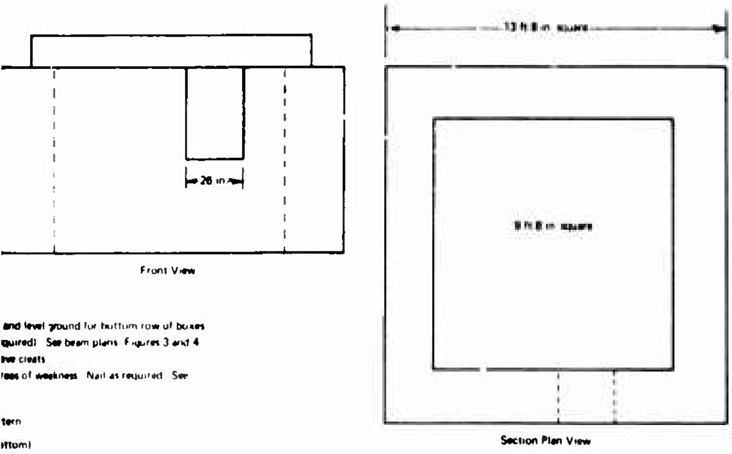


Note: All boxes are 106-mm

(b) Layout patterns A and B.

Figure 7. Construction plan for bunker made with

B



and level ground for bottom row of boxes
quired) See beam plans Figures 3 and 4
ive cleats
reas of weakness Nail as required See

tern

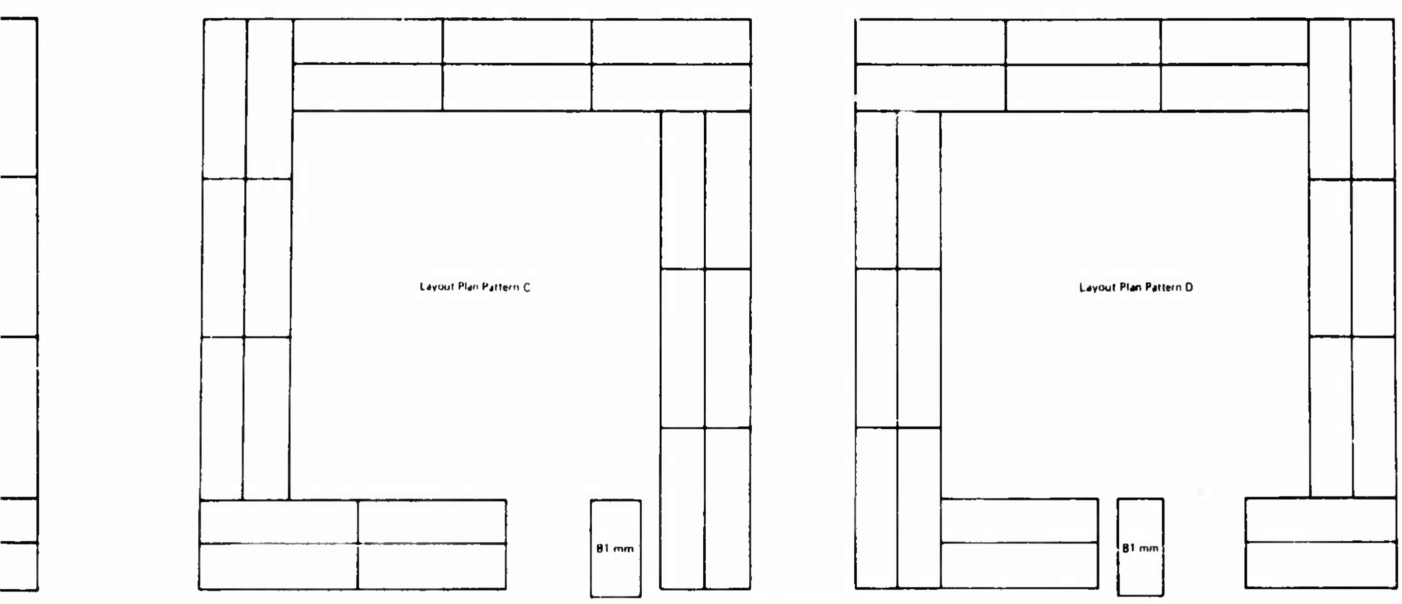
ttom)
B
A
B
A
B
C
D
C
D
C
D

quired with lids from other boxes
provide 2 feet of soil protection

Materials 106 mm boxes 380
81 mm boxes 6
nails - 10-penny 75 lb

Construction time 160 man hours, not including excavation of hole

a) Side, front, and section views.

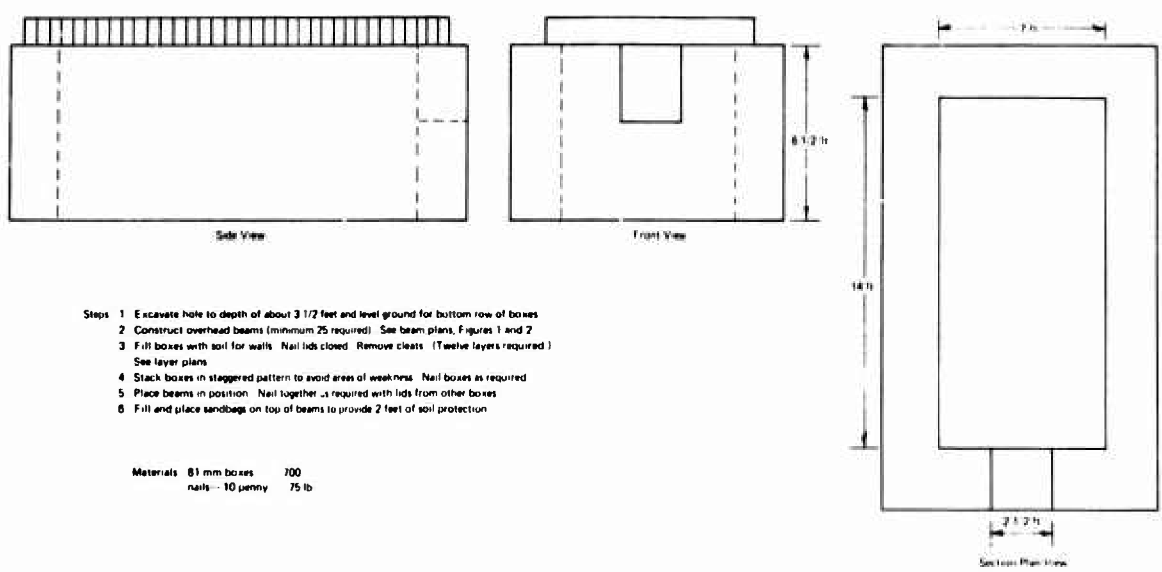


Notes 1 All boxes are 106 mm unless marked
2 Nail an 81 mm lid upside down on top of 81 mm box to increase height

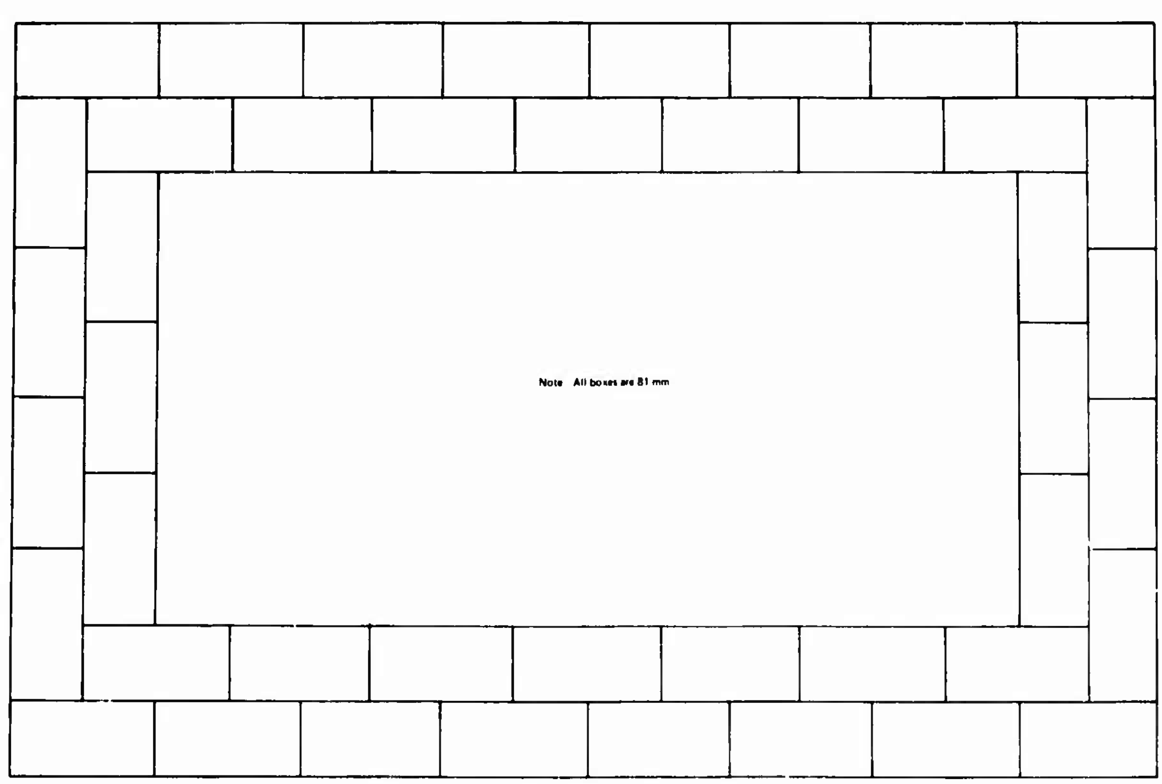
(c) Layout patterns C and D.

plan for bunker made with 106-mm ammunition boxes.

A



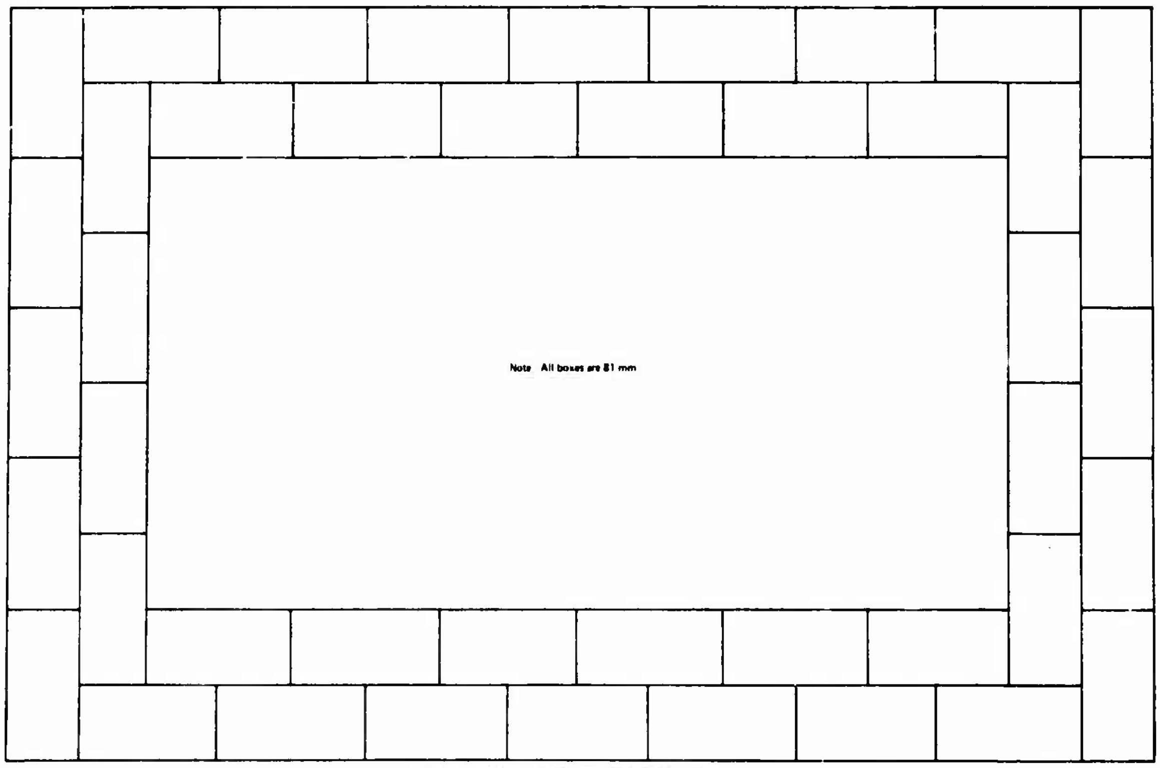
(a) Side, front, and section views.



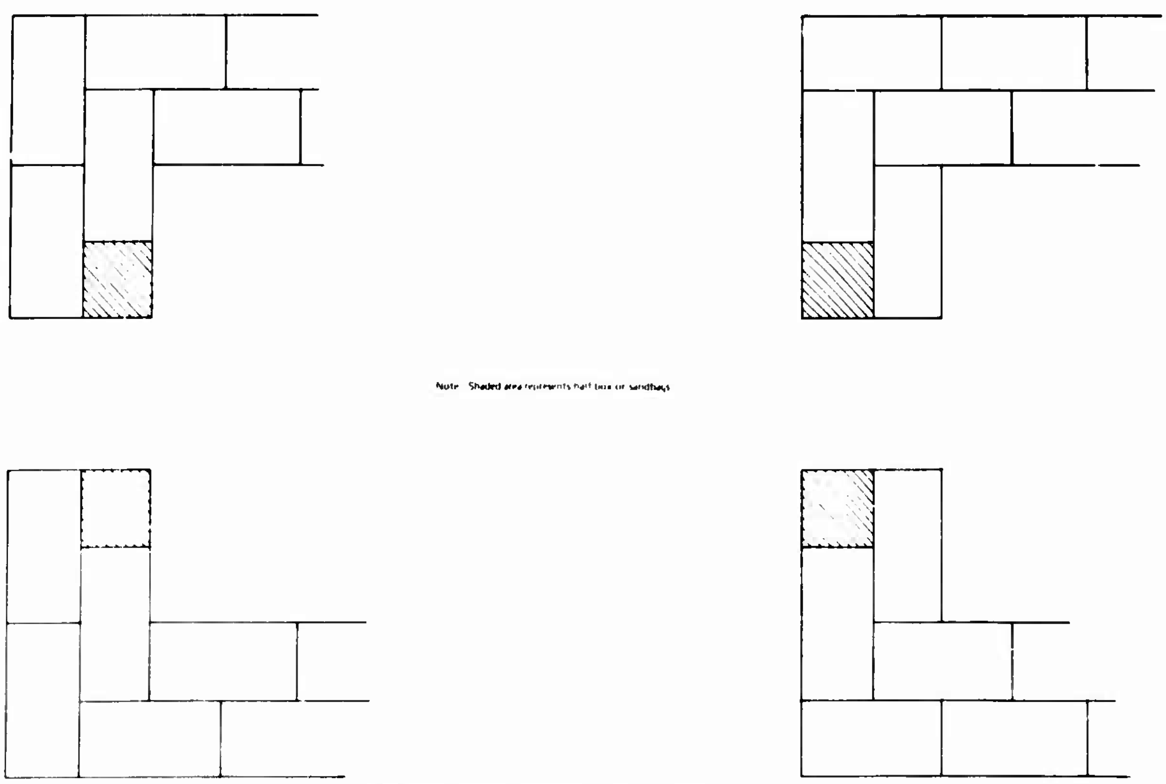
(c) Second layer.

Figure 8. Construction plan for bunker made with 8

1 B



(b) First and alternate layer.



(d) Entrance construction detail.

or bunker made with 81-mm ammunition boxes.

Figure 9. Bunker constructed with 106-mm ammunition boxes.

A similar bunker was constructed with 106-mm ammunition boxes and various munitions were exploded near it. Figure 10 summarizes the test results, giving the vulnerability of the structure. From an evaluation of the test data, the 2-foot wall thickness is capable of stopping all fragments from an 81-mm mortar round, all fragments from a 105-mm artillery round exploded at a distance greater than 18 feet, and all fragments from a 155-mm artillery round exploded at a distance greater than 25 feet. Additional protection may be obtained by stacking boxes around the outside of the above-ground portion of the bunker. This would increase the wall thickness in the above-ground portion to three boxes (36 inches of soil). A further discussion of the ordnance tests is presented in Appendix F.

SUMMARY

Various beam load tests have shown that it is possible to construct beams capable of safely carrying 2 feet of soil. Two specific designs are presented for beams which can span 7 and 10 feet carrying 2 feet of soil with a safety factor of 2. The problem of wood deterioration and loss of

beam strength has been investigated and found not to be very significant. Beams placed side by side can serve as foxhole covers. Soil stability data are presented to determine minimum bearing areas required.

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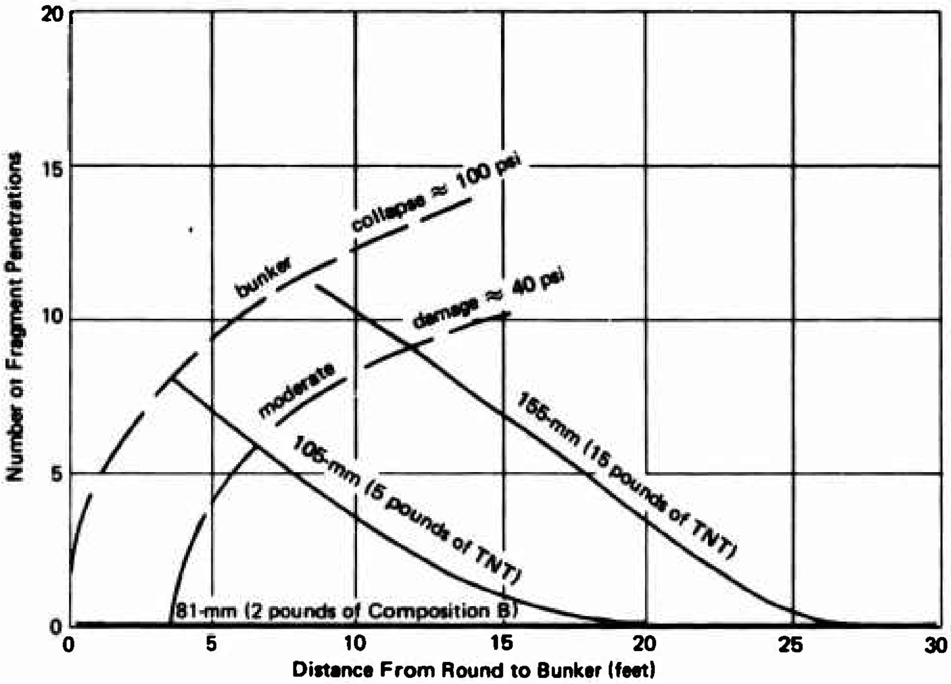


Figure 10. Evaluation of vulnerability of bunker to blast and fragmentation.

ACKNOWLEDGMENTS

Numerous NCEL personnel contributed to this effort. Mr. J. B. Crilly, Senior Project Scientist, prepared the adhesive used in fabrication of several beams; he also provided guidance on the preservation of wood. Dr. J. B. Forrest, Senior Project Engineer, prepared the soil slope stability data. Mr. C. E. Parker, NCEL Marine Corps Projects Officer, provided guidance on fragment penetration. Messrs. V. J. Gerwe, D. T. Corrente, J. R. Mooney, and L. J. Wolozynski, Engineering Technicians, fabricated the test beams.

The 31st Naval Construction Regiment constructed the bunker at Port Hueneme. Lieutenant Commander D. J. Biondo coordinated this effort. The 5th Marine Amphibious Brigade constructed the bunker at Camp Pendleton. Captain A. Karrer, USMC, Brigade Engineer, coordinated this effort, and Lieutenant T. Bruster, USMC, supervised construction.

The author is most appreciative of the assistance and cooperation of all of the people involved.

Appendix A

LOAD TESTS OF BEAMS MADE FROM 81-mm MORTAR AMMUNITION BOXES

BEAM CONSTRUCTION

Various methods of joining boxes together to form a beam were tried and evaluated. Table A-1 contains basic construction data, giving materials, tools, and man-hours required to construct each beam in a typical field condition. The box for 81-mm mortar rounds is shown in Figure A-1. All of the beams in this appendix were made from this type of box. The outside dimensions of the 81-mm mortar ammunition box are 27 inches long, 14 inches wide, and 6 inches high.

Beam 1

Two boxes were disassembled and their sides, tops, and bottoms were nailed to join three other boxes together (Figure A-2). This beam was tested along its major axis (Beam 1) and along its minor axis (Beam 1A). All nails in this and other beams were 10-penny.

Table A-1. Construction Data for Beams Made From 81-mm Ammunition Boxes

Beam No.	No. of Boxes	Additional Materials	Tools	Construction Time (man-hr)
1	5	160 nails[a]	hammer	1.5
2	4	100 nails; 3 steel straps	hammer; banding machine	2.0
3	7	160 nails	hammer	2.0
4	7	60 nails; adhesive	hammer; spatula	1.5
5	3	*b*	*b*	0.1
6	3	*b*	*b*	0.1
7	6	200 nails	hammer	2.0
8	7	450 nails	hammer	2.0

[a] All nails were 10-penny.

[b] Assumes hinges are factory installed.

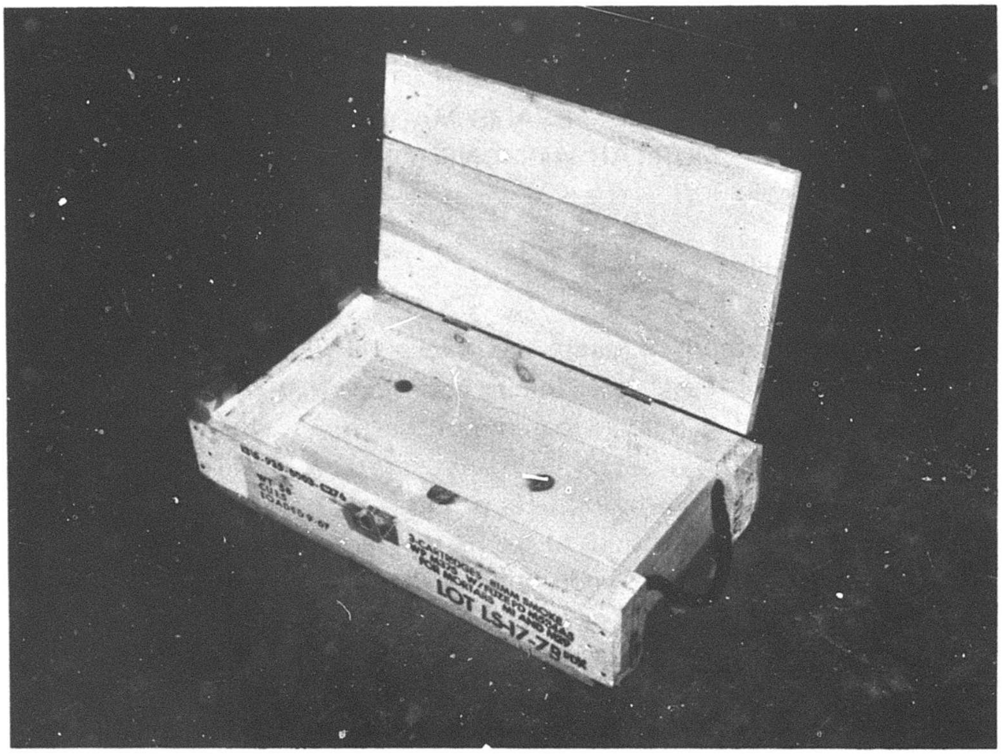


Figure A-1. Box for 81-mm mortar ammunition.

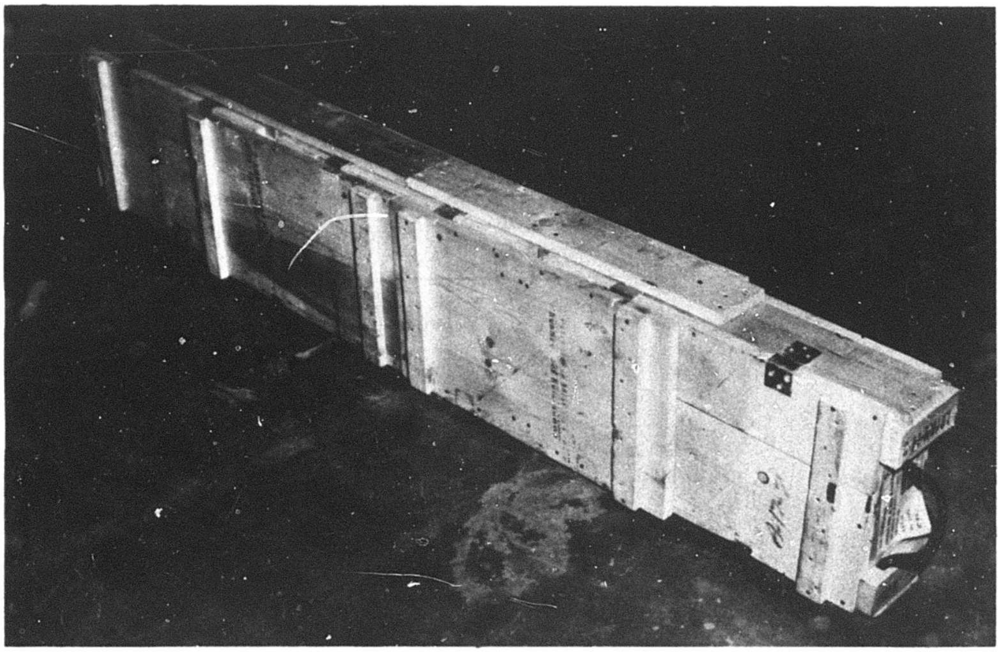


Figure A-2. Beam 1, 81-mm ammunition boxes.

Beam 2

A box was disassembled and the sides were nailed to the compression face of a beam composed of three other boxes. A steel band was placed around the three boxes, and two steel bands were nailed to the tension face (Figure A-3). The lids of the three boxes were nailed closed.

Beam 3

The lids from seven boxes were removed and the boxes were nailed back to back in a staggered pattern of four and three boxes. The lids from six boxes were used as cover plates on the tension and compression faces (Figure A-4). This beam resembles a wide-flange shape in cross section, two boxes wide.

Beam 4

Seven boxes were joined together by adhesive, back to back, in a staggered four and three box pattern. The boxes were nailed together to provide contact until the adhesive hardened. The lids were glued and nailed to the boxes (Figure A-5). The adhesive, DM1512, and its activator, DM1513, are manufactured by Admiral Paint Company as an underwater curing epoxy. The cost of the adhesive per beam was about $3.00.

Beam 5

Hinge-halves were screwed to both sides of three boxes. Boxes were connected together by mating hinge-halves and secured by hinge pins (Figures A-6 and A-7). No additional material was used. The lids of the three boxes were secured only by the box hasp.

Beam 6

Hinge-halves were connected to a metal strap and screwed to both sides of three boxes. Mating hinge-halves connected the boxes together as shown in Figures A-8 and A-9. No other material was used. The lids of the boxes were secured only by the box hasp.

Beam 7

Twelve lids and bottoms from six boxes were used to make a beam 3 inches wide by 14 inches deep (Figure A-10). The beam was composed of four layers of three pieces each. Each layer was alternately offset one-quarter of a box and nailed to the preceding layer.

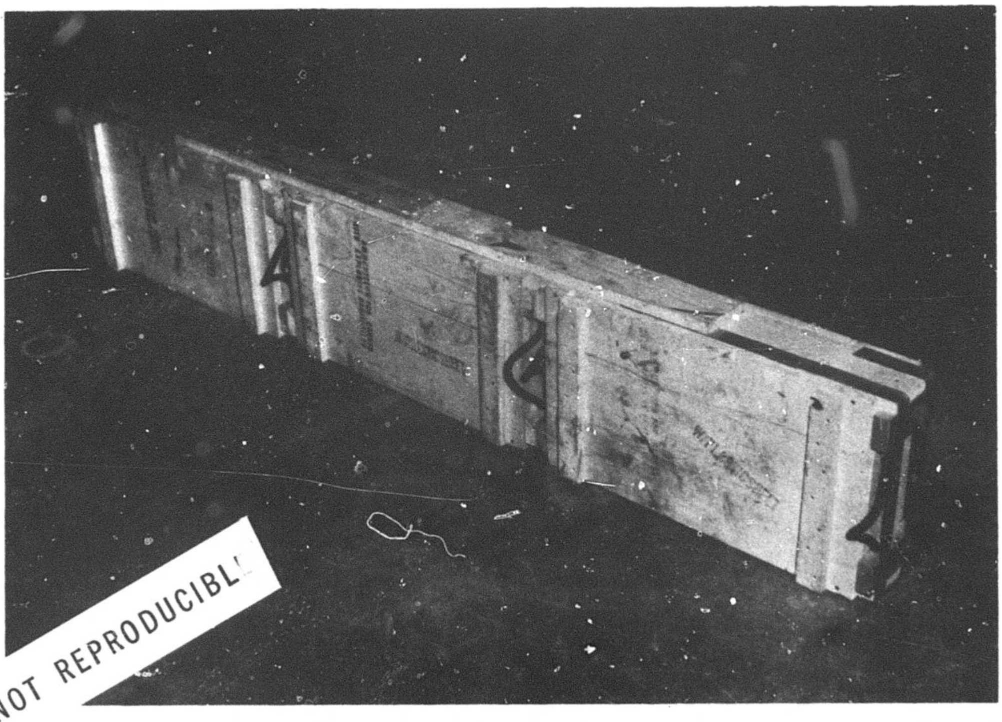


Figure A-3. Beam 2, 81-mm ammunition boxes.

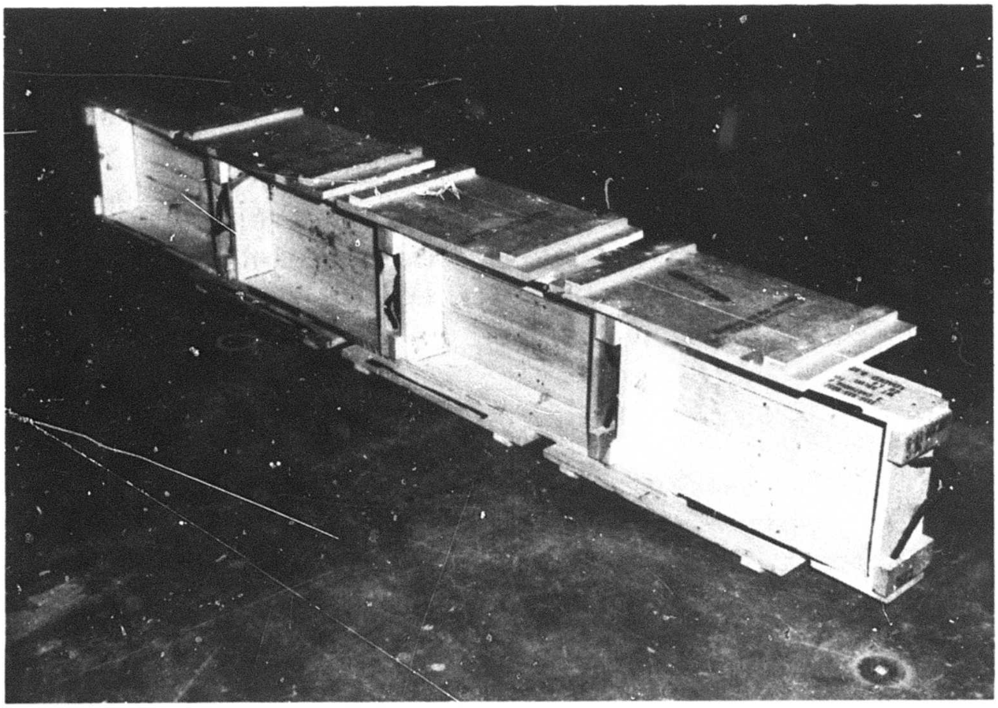


Figure A-4. Beam 3, 81-mm ammunition boxes.

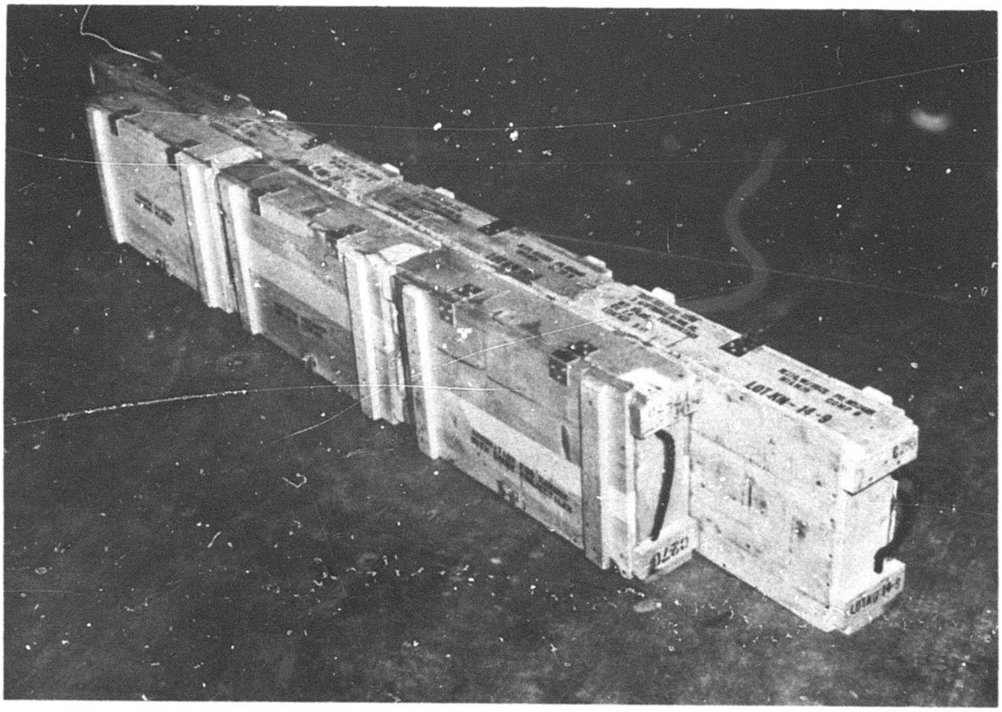


Figure A-5. Beam 4, 81-mm ammunition boxes.

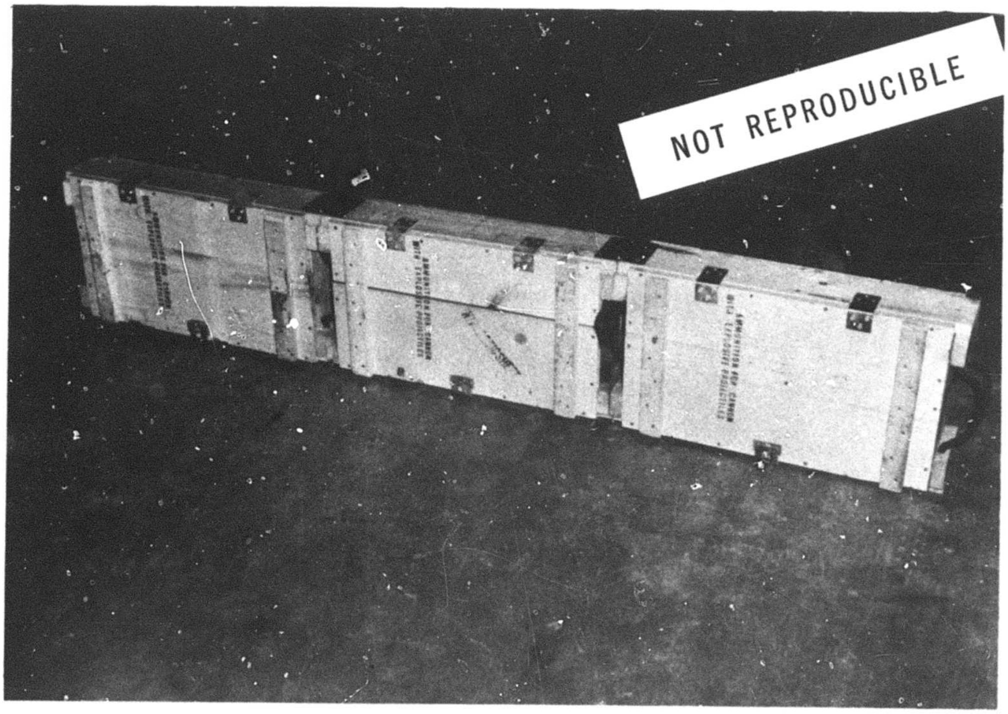


Figure A-6. Beam 5, 81-mm ammunition boxes.

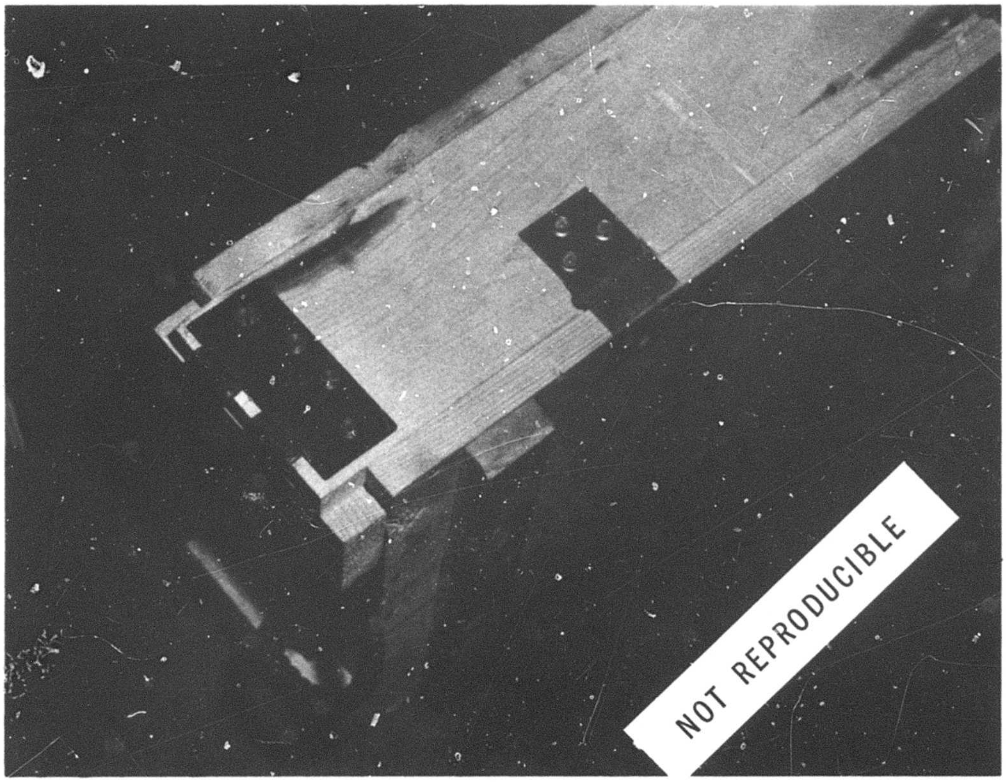


Figure A-7. Beam 5, 81-mm ammunition boxes (detail).

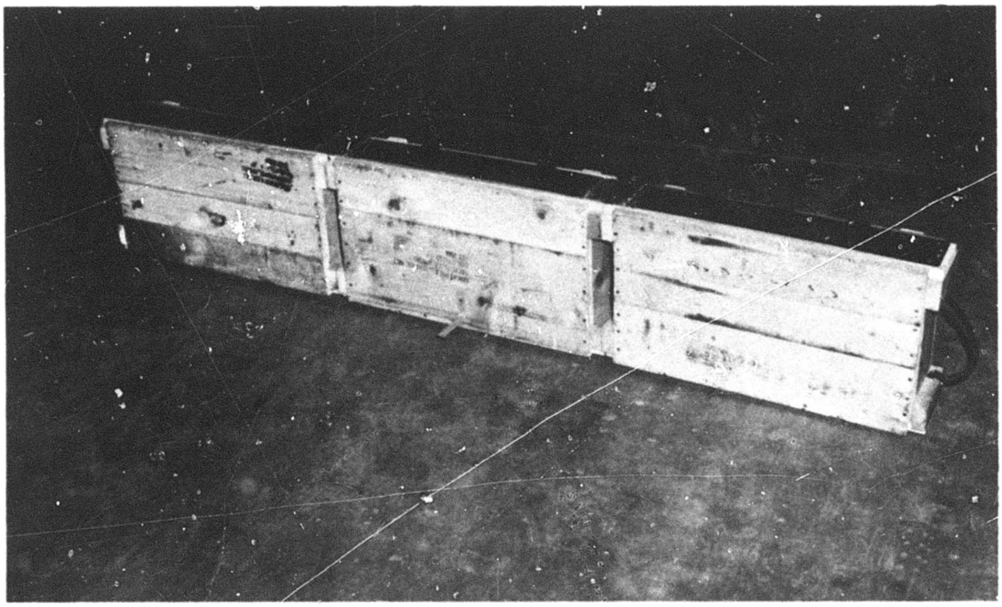


Figure A-8. Beam 6, 81-mm ammunition boxes.

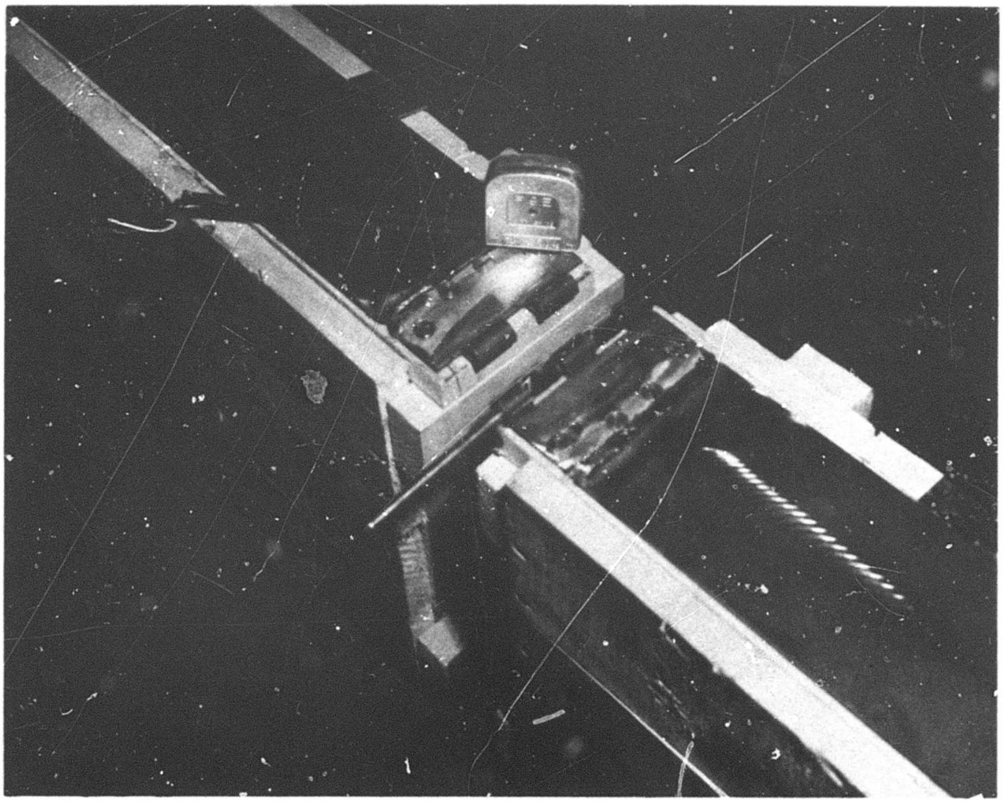


Figure A-9. Beam 6, 81-mm ammunition boxes (detail).

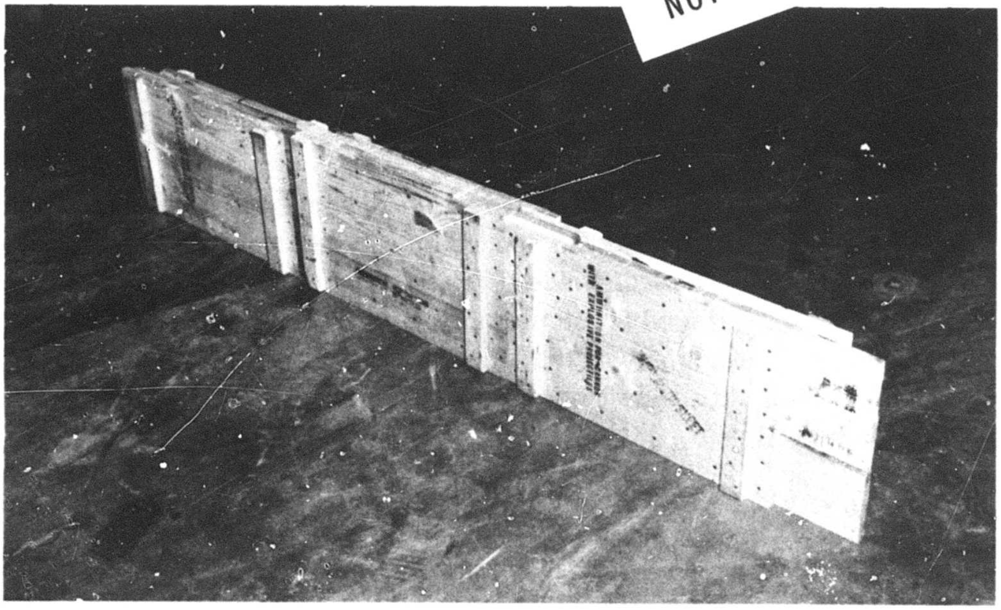


Figure A-10. Beam 7, 81-mm ammunition boxes.

Beam 8

Three boxes were disassembled and the sides, tops, and bottoms were nailed to join four other boxes together (Figure A-11). This beam was similar to Beam 1 with the addition of one box in length; however, additional nailing was provided to make it more rigid.

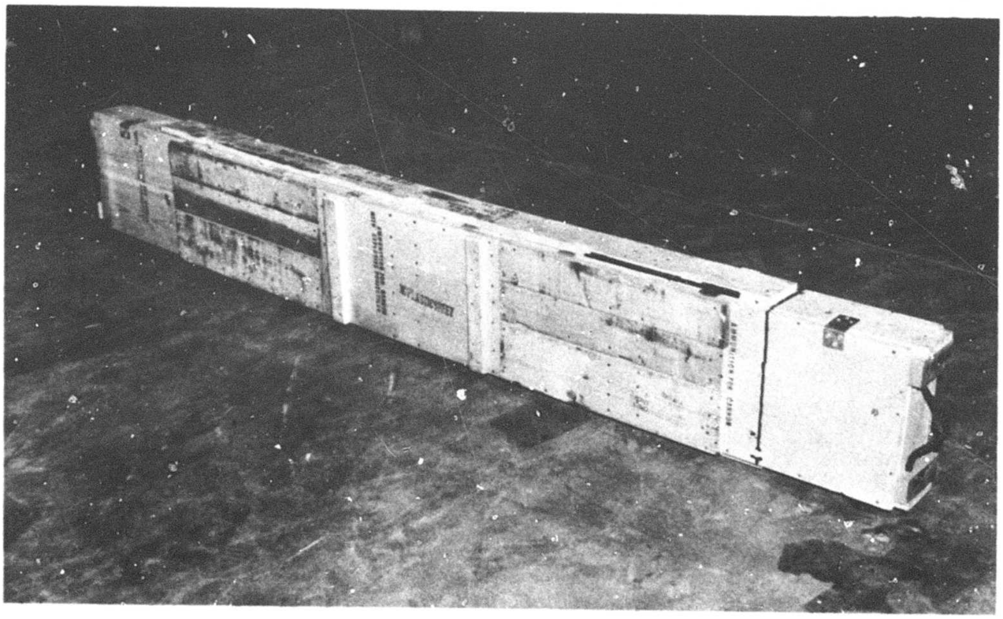


Figure A-11. Beam 8, 81-mm ammunition boxes.

TEST PROCEDURE AND RESULTS

In each test, two concentrated loads were applied to a simply supported beam (Figure A-12). The load was applied by a hydraulic ram and measured by a load cell. Centerline deflections were observed and recorded. A span length of 62 to 68 inches was used for all beams except for Beam 8, for which it was about 88 inches. A summary of the ultimate loads and modes of failure is given in Table A-2. Load–deflection curves for each beam are given in Figures A-13 through A-21.

STRUCTURAL CAPACITY

The quality of the wood used in box construction was poor. Nails driven into the soft wood pulled out easily. The major limitation in the strength of the intact box is its excessive racking. This results from the

pull-out failure of the nails joining the box lids and bottoms to the end pieces. This is most significant in the single row of boxes joined by hinges (Beams 5 and 6) or bands (Beam 2). Placing additional pieces nailed along the sides of the beams across the box joints substantially increases the strength of the beams (Beams 1 and 8). The stiffness and strength of the beam depend significantly on the extent of the nailing and the pattern used. However, even with substantial nailing, the boxes still behave somewhat as individual components. It was only in the beam joined by adhesive, Beam 4, that true stress transfer was achieved. This is demonstrated by the very small center-line deflection observed.

The wooden wide-flange section, essentially equivalent to a 2- by 14-inch board, also was limited by box slippage, resulting in excessive deflection. The nails joining the boxes back to back pulled out under loading.

The layered beam resembling a 3- by 14-inch board, Beam 7, would have very high strength if the compression face were laterally restrained. Lacking this side stiffness, its load capacity is limited by buckling of the compression zone. Box side pieces could be used for cross bracing.

Table A-2. Summary of Results of Beam Load Tests

Beam No.	Total Failure Load (lb)	Failure Mode	Failure Moment (in.-kips)	Equivalent Ultimate Distributed Load (lb/ft of length)
1	3,000	racking	30.99	773
1A	850	excessive deflection	9.78	203
2	1,600	racking	16.53	413
3	2,200	excessive deflection	28.33	707
4	6,300	shear/splitting	72.45	1,250
5	1,000	racking	11.00	274
6	1,100	racking	12.00	300
7	2,500	lateral buckling	27.50	687
8	3,000	racking	52.50	650

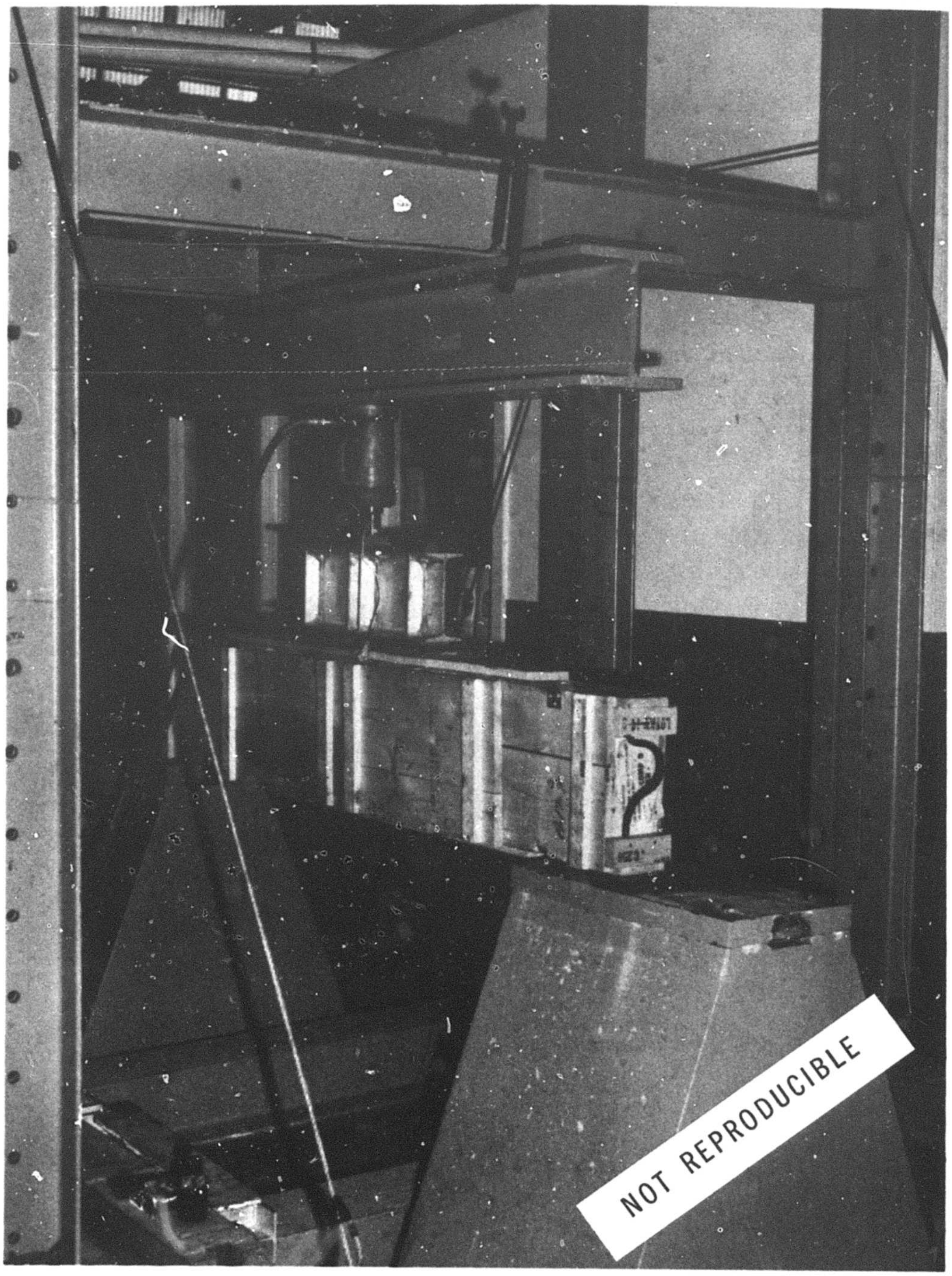


Figure A-12. Apparatus for load tests.

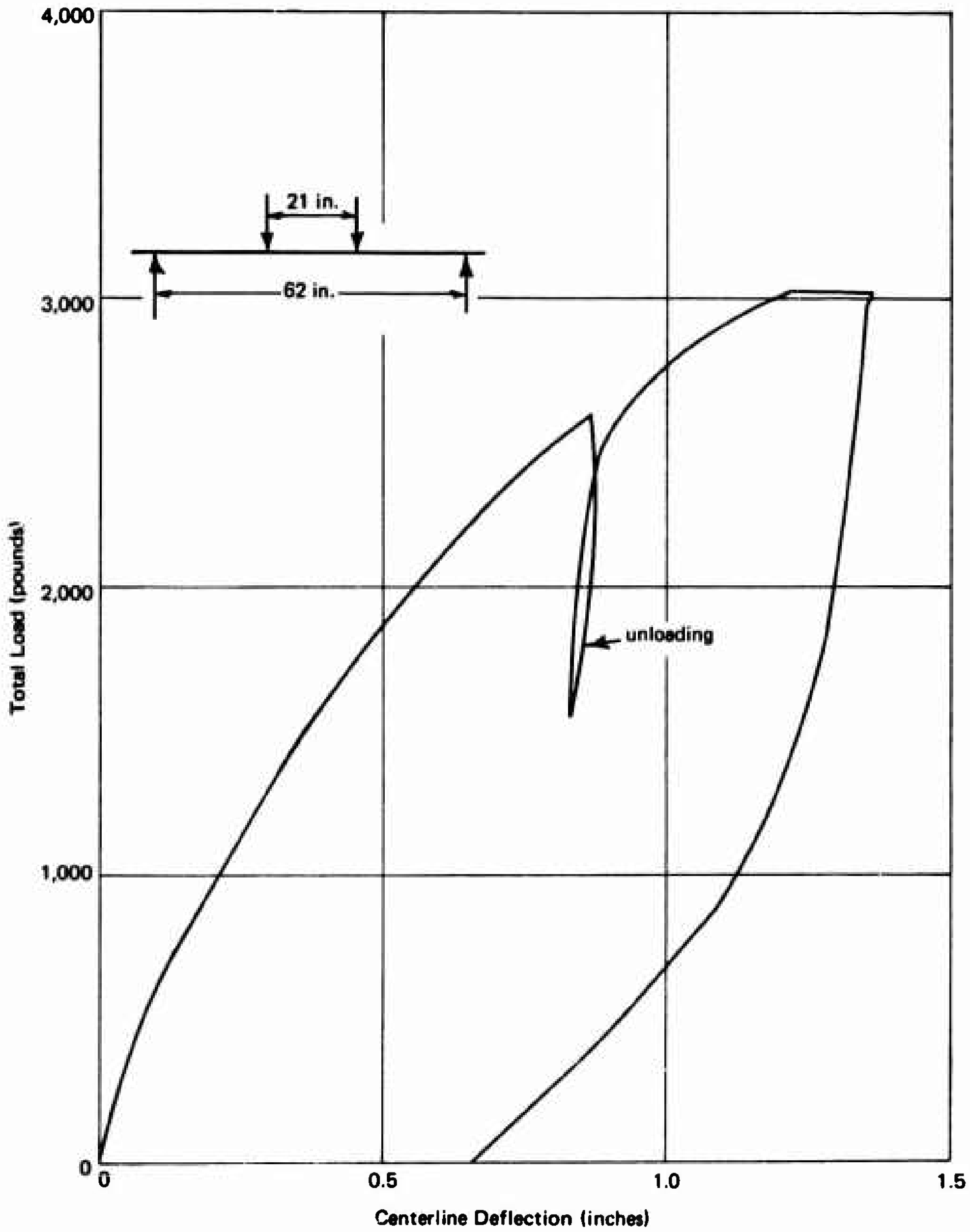


Figure A-13. Load–deflection curve, Beam 1, 81-mm ammunition boxes.

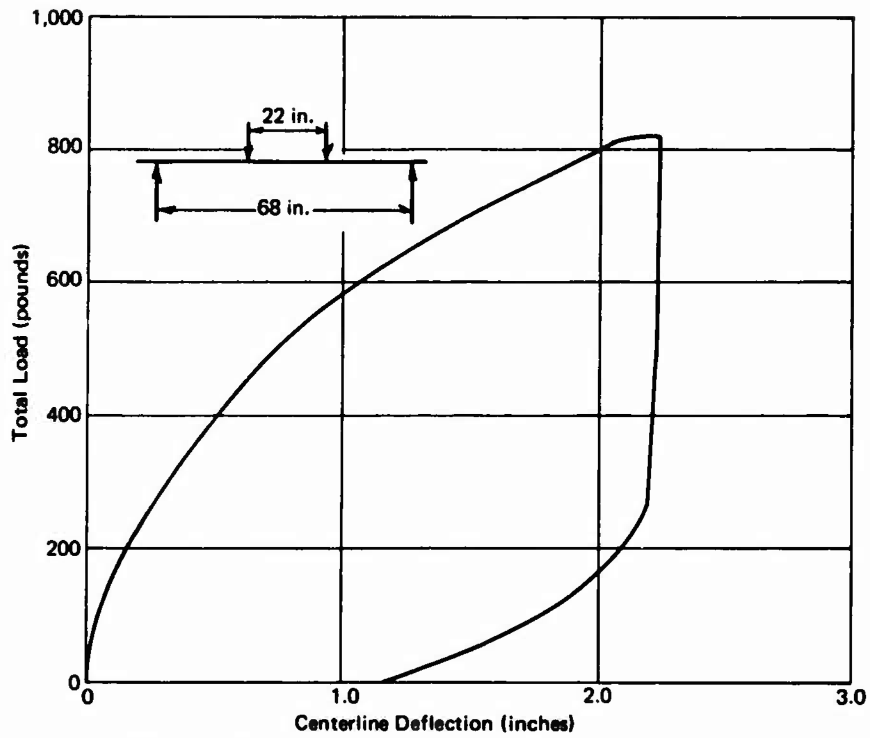


Figure A-14. Load–deflection curve, Beam 1A (minor axis), 81-mm ammunition boxes.

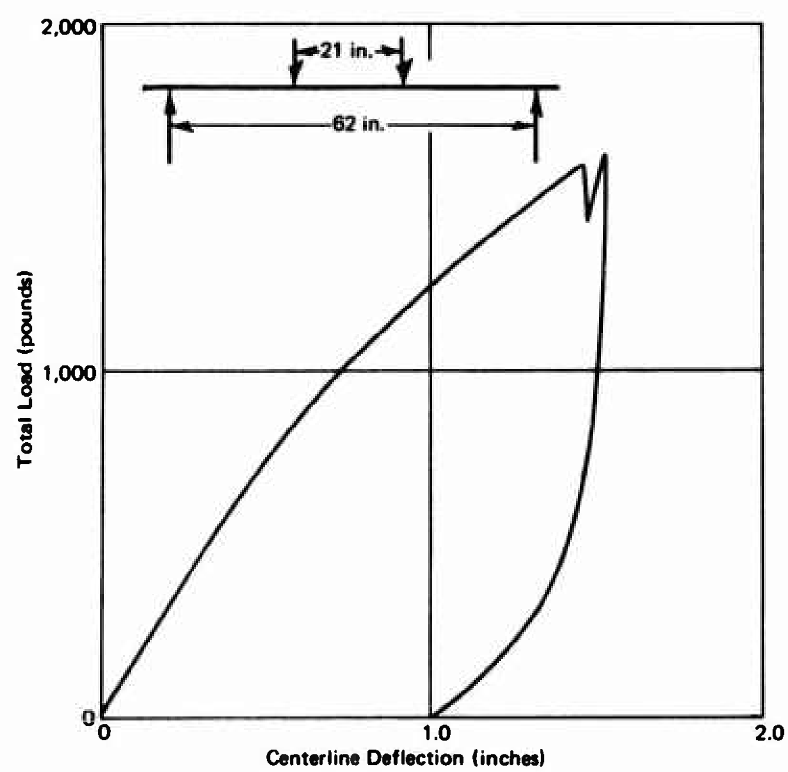


Figure A-15. Load–deflection curve, Beam 2, 81-mm ammunition boxes.

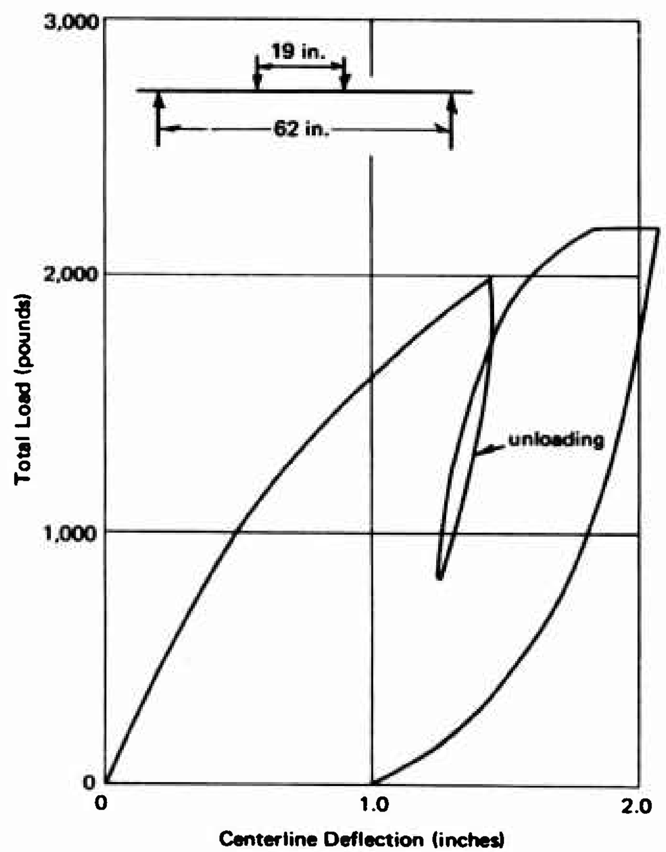


Figure A-16. Load—deflection curve, Beam 3, 81-mm ammunition boxes.

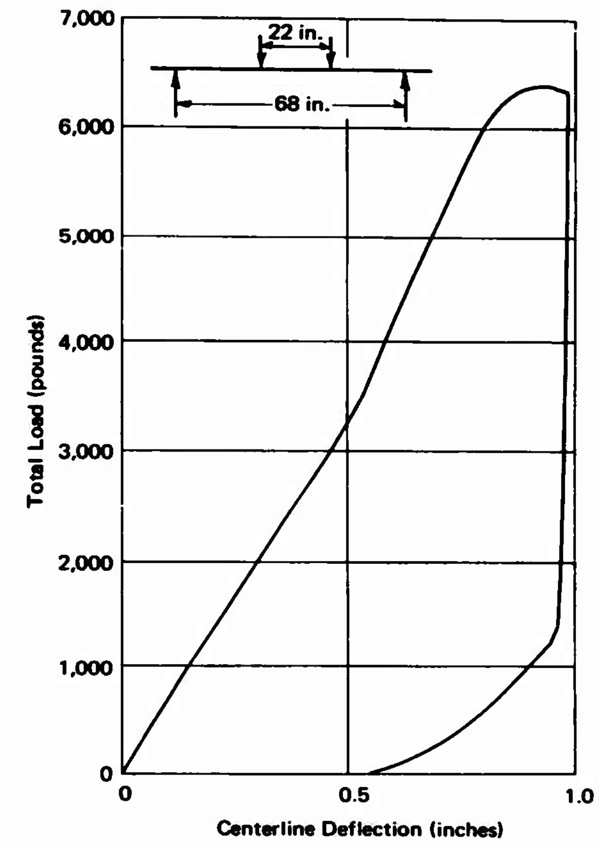


Figure A-17. Load—deflection curve, Beam 4, 81-mm ammunition boxes.

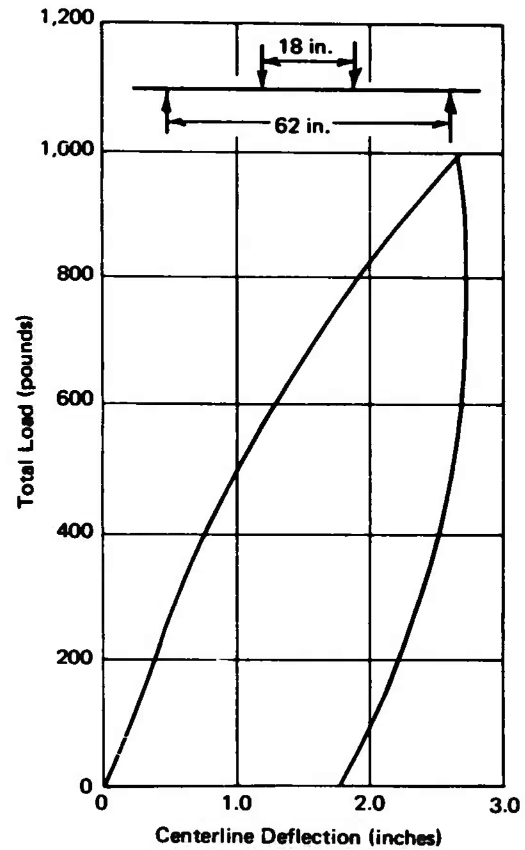


Figure A-18. Load—deflection curve, Beam 5, 81-mm ammunition boxes.

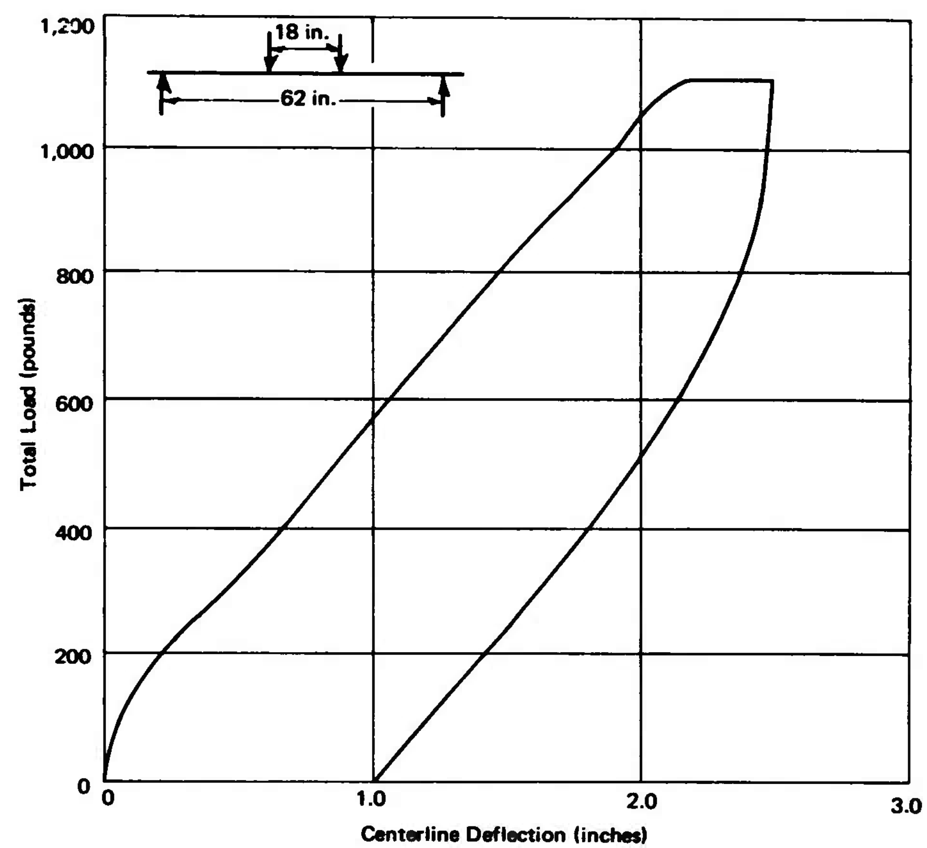


Figure A-19. Load—deflection curve, Beam 6, 81-mm ammunition boxes.

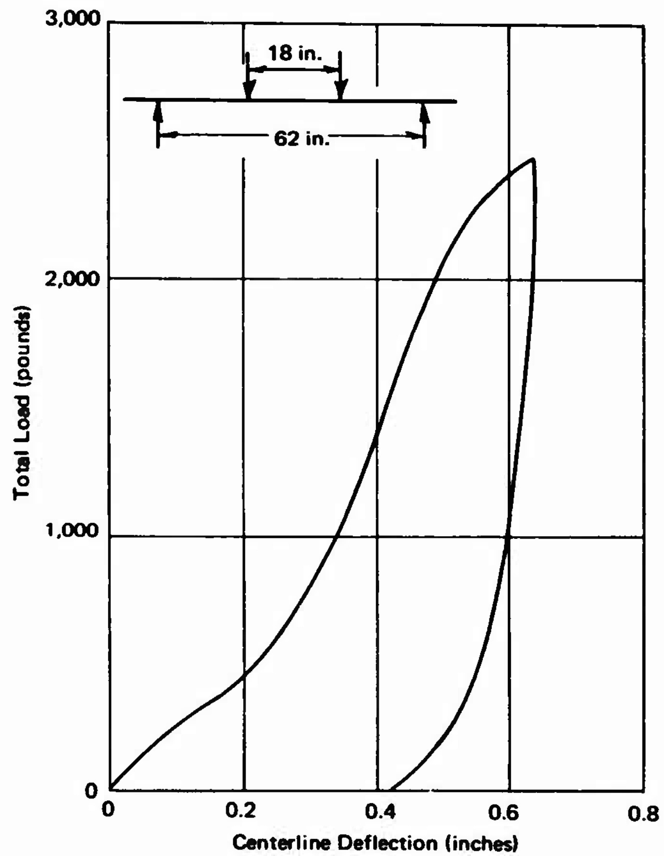


Figure A-20. Load–deflection curve, Beam 7, 81-mm ammunition boxes.

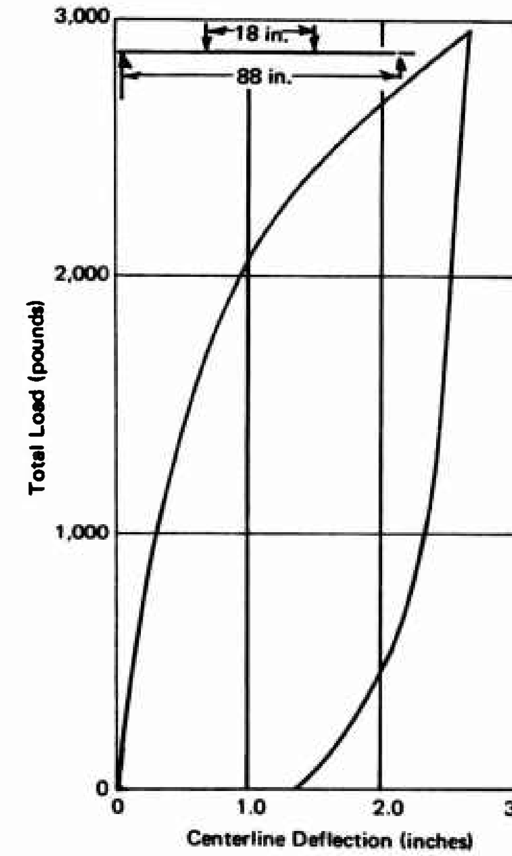


Figure A-21. Load–deflection curve, Beam 8, 81-mm ammunition boxes.

The beams tested along their minor axes lack sufficient stiffness to be used directly over a 5-foot span to support 2 feet of soil.

The strength of the boxes connected by hinges could be improved if the lids were nailed; however, the advantage of construction in the field without any tools or materials is then lost. It is assumed that the installation of the hinges would be accomplished at the factory. The box should be designed so that the hinge is built into the box in double shear rather than attached to the surface in single shear. The current construction of the box lacks sufficient precision to assure a consistently tight fit when the boxes are connected together.

PROTECTIVE CONSTRUCTION WITH BEAMS

Beams 1 through 7, described above, can be used to form the overhead protection of a bunker having about a 5-foot clear span. Beam 8 is based on a 7-foot span. Individual boxes can be filled with soil and placed on top of the beams as decking for 2 feet of protection. A total safe load of 250 psf of surface area with a safety factor of 2.0 will be used for comparison. Based on this, Table A-3 gives the maximum allowable center-to-center spacing of the beams tested. An individual box on a 20-inch span has been tested and found capable of carrying a 7,000-pound concentrated load, so it is more than adequate.

Table A-3. Maximum Allowable Center-to-Center Spacing

Beam No.	Maximum Allowable Spacing[a] (in.)
1	18
1A	not allowed
2	10
3	17
4	30
5	7
6	7
7	16
8	15

[a] Based on a load of 250 psf with a safety factor of 2.0 (equivalent to approximately 2 feet of earth).

An alternative approach for greater load capacity places the beams next to each other without any space between them. This approach is recommended for bunker construction. Table A-4 gives the beam capacity in pounds per square foot with a safety factor of 2.0 for the beams placed side by side. The span considered is as stated above: 5 feet for Beams 1 through 7, and 7 feet for Beam 8.

Table A-4. Safe Load for Beams Placed Side by Side

Beam No.	Individual Beam Width (in.)	Safe Load[a] (psf)	Equivalent Depth of Soil Cover (ft)
1	8-1/2	550	4.4
1A	14	90	0.7
2	6-3/4	370	2.9
3	14	260	2.1
4	14	540	4.3
5	6-3/4	240	1.9
6	6-3/4	270	2.1
7	3	1,370	11.0
8	6-3/4	580	4.6

[a] Safety factor = 2.0.

Appendix B

LOAD TESTS OF BEAMS MADE FROM 106-mm RECOILLESS RIFLE AMMUNITION BOXES

BEAM CONSTRUCTION

Several of the more advantageous concepts developed for joining 81-mm mortar ammunition boxes together were tried with 106-mm recoilless rifle ammunition boxes. The 106-mm ammunition box is about the same width and height as the 81-mm ammunition box but about 1.6 times as long. The outside dimensions of the 106-mm recoilless rifle ammunition box are length 45-1/2 inches, width 13 inches, and height 8 inches. All of the beams in this appendix were made from this type of box. The box is shown in Figure B-1. The same beam designations used in Appendix A to describe the methods of joining the boxes together are used here.

Beam 1

Two boxes were disassembled and their sides, tops, and bottoms were nailed to join three other boxes together (Figure B-2). All nails in this and other beams were 10-penny.

Beam 4

Seven boxes were joined together back to back in a staggered four and three box pattern by adhesive. The boxes were nailed together to provide contact until the adhesive hardened. The lids were glued and nailed to the boxes (Figure B-3). The adhesive was the same as that described in Appendix A for Beam 4.

Beam 5

Hinge-halves were screwed to both ends of both sides of three boxes. Boxes were connected together by mating hinge-halves and secured by hinge pins (Figure B-4). No additional material was used. The lids of the three boxes were secured only by the box hasp.

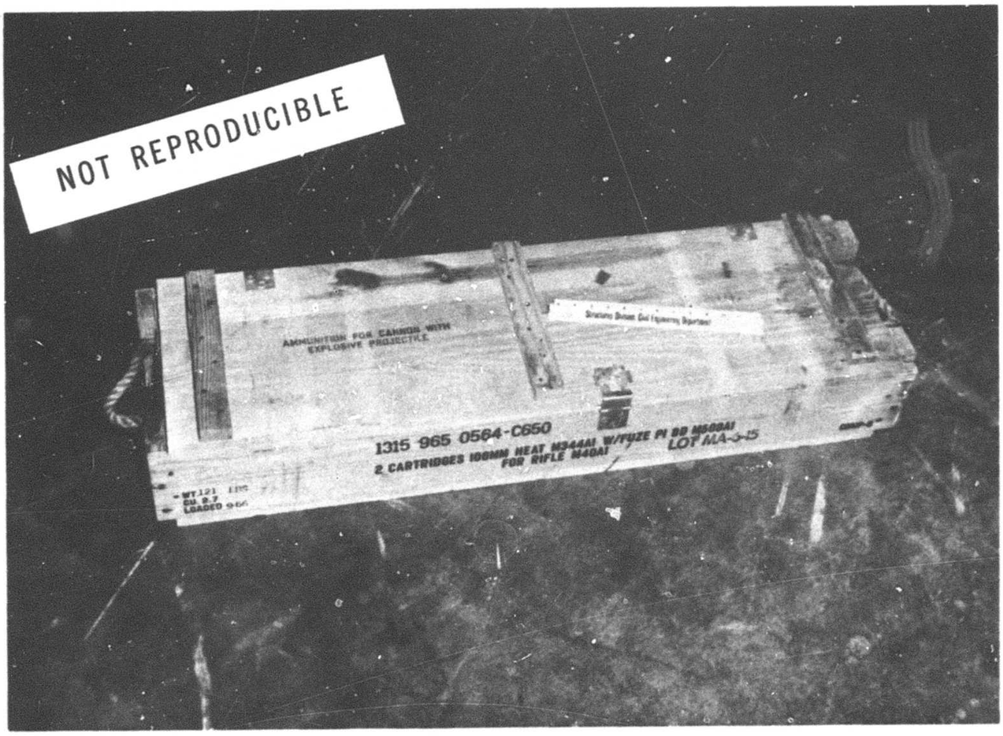


Figure B-1. Box for 106-mm recoilless rifle ammunition.

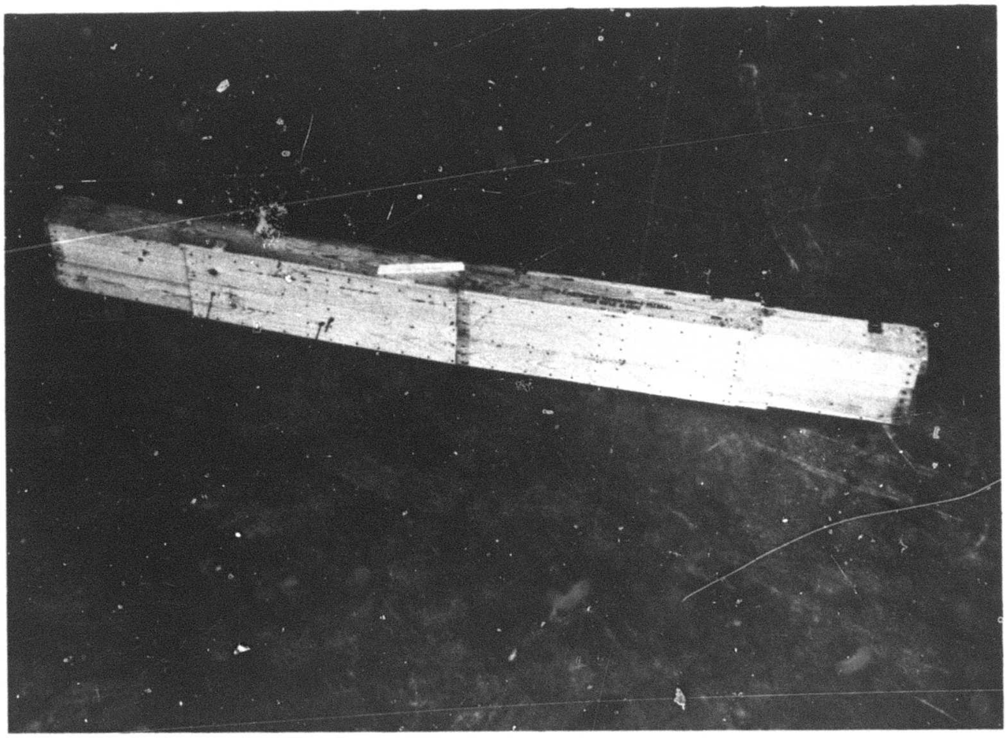


Figure B-2. Beam 1, 106-mm ammunition boxes.

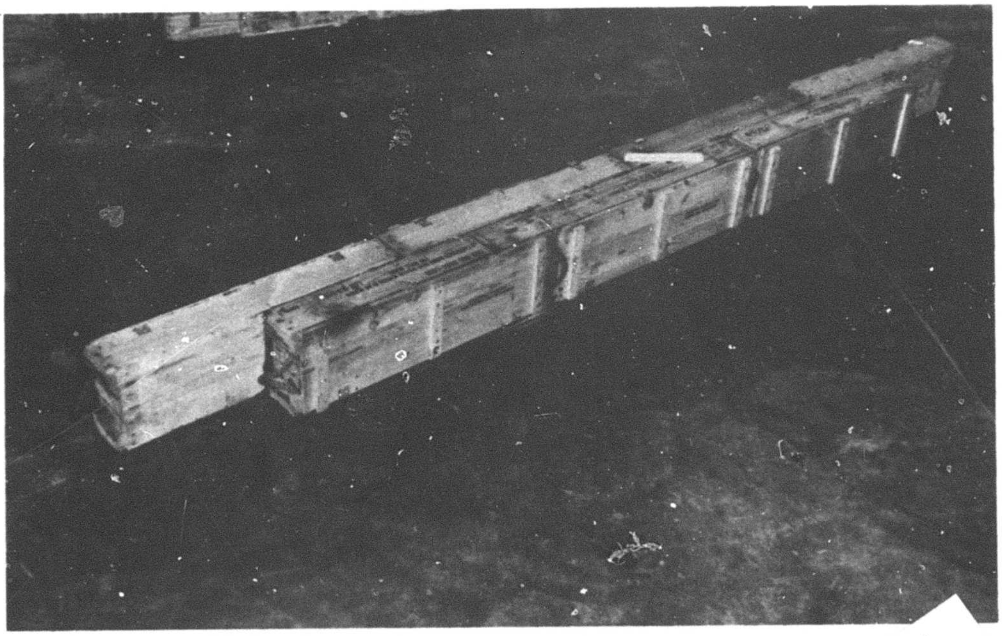


Figure B-3. Beam 4, 106-mm ammunition boxes.

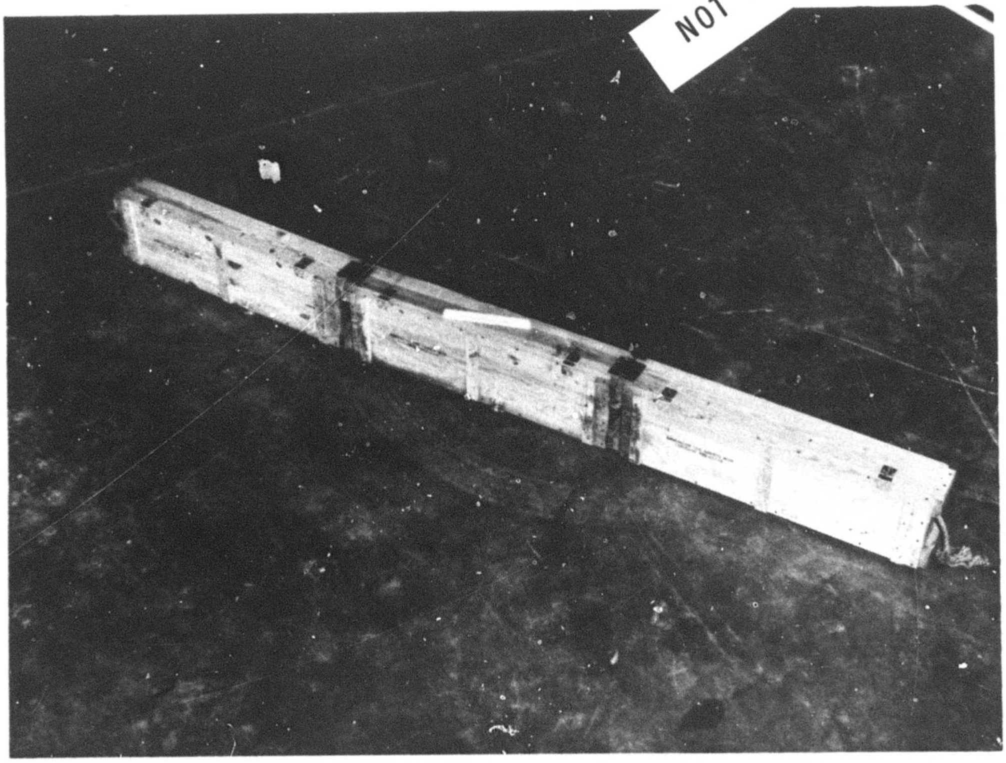


Figure B-4. Beam 5, 106-mm ammunition boxes.

Beam 1-4

This method combined the technique used to make Beam 1 and added the use of adhesive. Two boxes were disassembled and their sides, tops, and bottoms were coated with an adhesive and nailed to join three other boxes together. This beam resembles Beam 1, Figure B-2.

Table B-1 contains basic construction data, giving materials, tools, and man-hours required to construct each beam in a typical field condition.

Table B-1. Construction Data for Beams Made From 106-mm Ammunition Boxes

Beam No.	No. of Boxes	Additional Materials	Tools	Construction Time (man-hr)
1	5	262 nails[a]	hammer	2
4	7	60 nails; adhesive	hammer; spatula	2
5	3	[b]	[b]	0.1
1-4	5	262 nails; adhesive	hammer; spatula	2

[a] All nails were 10-penny.

[b] Assumes hinges factory installed.

TEST PROCEDURE AND RESULTS

The beams were tested with the same procedure described in Appendix A. The span length was 10 feet. A summary of the ultimate loads and modes of failure is given in Table B-2. Load–deflection curves for each beam are given in Figures B-5 through B-8.

Structural Capacity

The quality of wood used in the 106-mm ammunition boxes was poor, similar to that of the 81-mm ammunition boxes. The beam joined by hinges had excessive deflection caused by the racking of individual boxes. Beam 4

was limited by the strength of the box, although the adhesive performed satisfactorily. The box bottoms joined together by adhesive to resemble a 2- by 14-inch board behaved as a unit; however, the nailing between the box bottoms and the sides failed. This beam was very long and difficult to handle. Beam 1 performed satisfactorily. Beam 1-4, of similar construction to Beam 1 with the addition of adhesive, was able to carry more than twice the load of Beam 1. Additionally, it was significantly stiffer than Beam 1, behaving more as a single unit.

PROTECTIVE CONSTRUCTION WITH BEAMS

The beams described above can be used to form the overhead protection of a bunker with a clear span up to 10 feet. A total safe load of 250 psf of surface area and a safety factor of 2.0 will be used for comparison. Based on this, Table B-3 gives the maximum allowable center-to-center spacing of the beams.

An alternative approach for greater load capacity places the beams next to each other without any space between them. Table B-4 gives the beam capacity in pounds per square foot with a factor of safety of 2.0 for the beams placed side by side.

Table B-2. Summary of Results of Beam Load Tests

Beam No.	Total Failure Load (lb)	Failure Mode	Failure Moment (in.-kips)	Equivalent Ultimate Distributed Load (lb/ft of length)
1	2,200	racking	53.0	358
4	2,900	splitting	71.0	487
5	800	racking	19.6	130
1-4	4,800	splitting	117.0	784

Table B-3. Maximum Allowable Center-to-Center Spacing

Beam No.	Maximum Allowable Spacing[a] (in.)
1	8.5
4	not allowed
5	not allowed
1-4	19.0

[a] Based on a load of 250 psf with a safety factor of 2.0 (equivalent to approximately 2 feet of earth).

Table B-4. Safe Load for Beams Placed Side by Side[a]

Beam No.	Individual Beam Width (in.)	Safe Load (psf)	Equivalent Depth of Soil Cover (ft)
1	8-1/2	250	2.0
4	16	180	1.5
5	8	100	0.8
1-4	8-1/2	550	4.4

[a] Safety factor = 2.0.

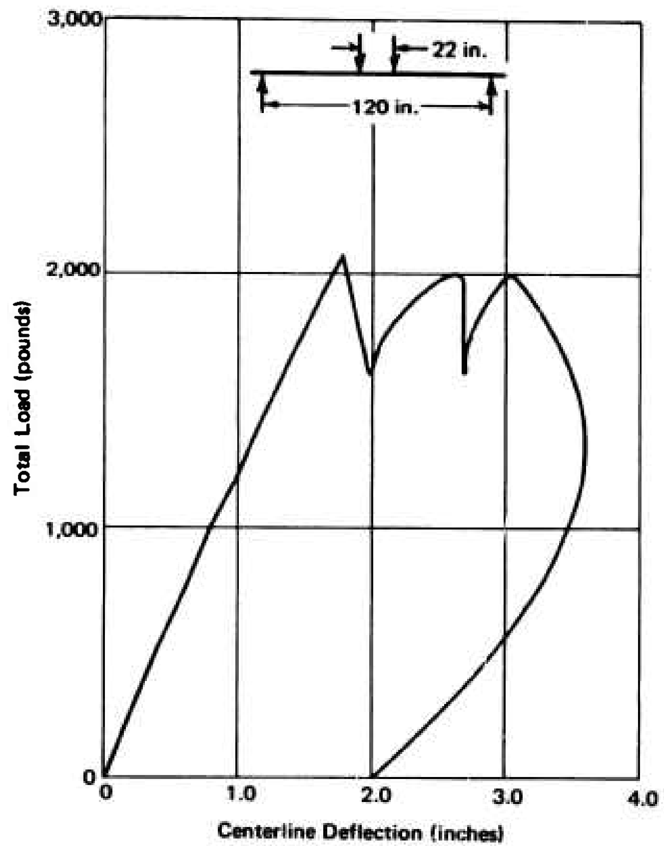


Figure B-5. Load—deflection curve, Beam 1, 106-mm ammunition boxes.

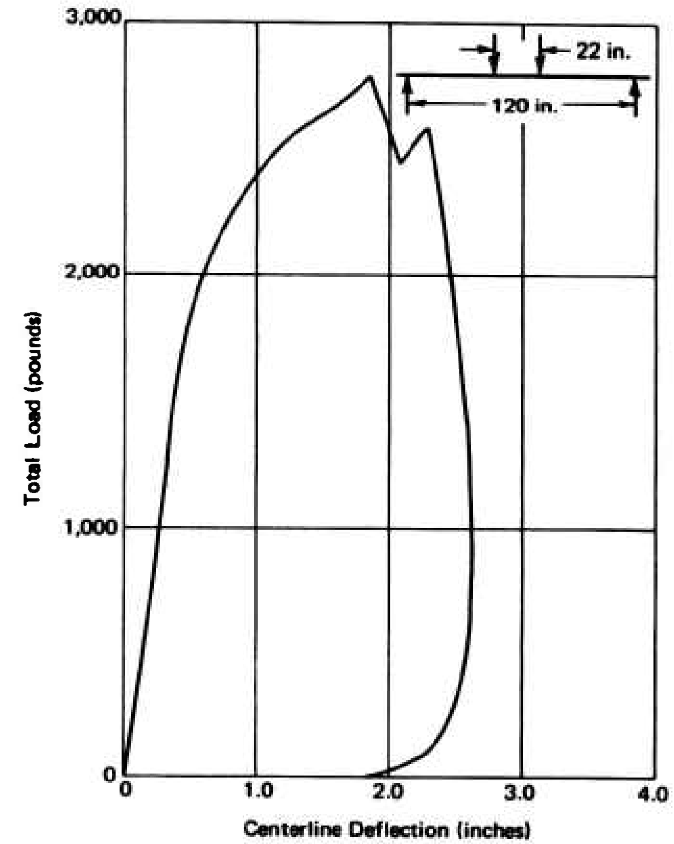


Figure B-6. Load—deflection curve, Beam 4, 106-mm ammunition boxes.

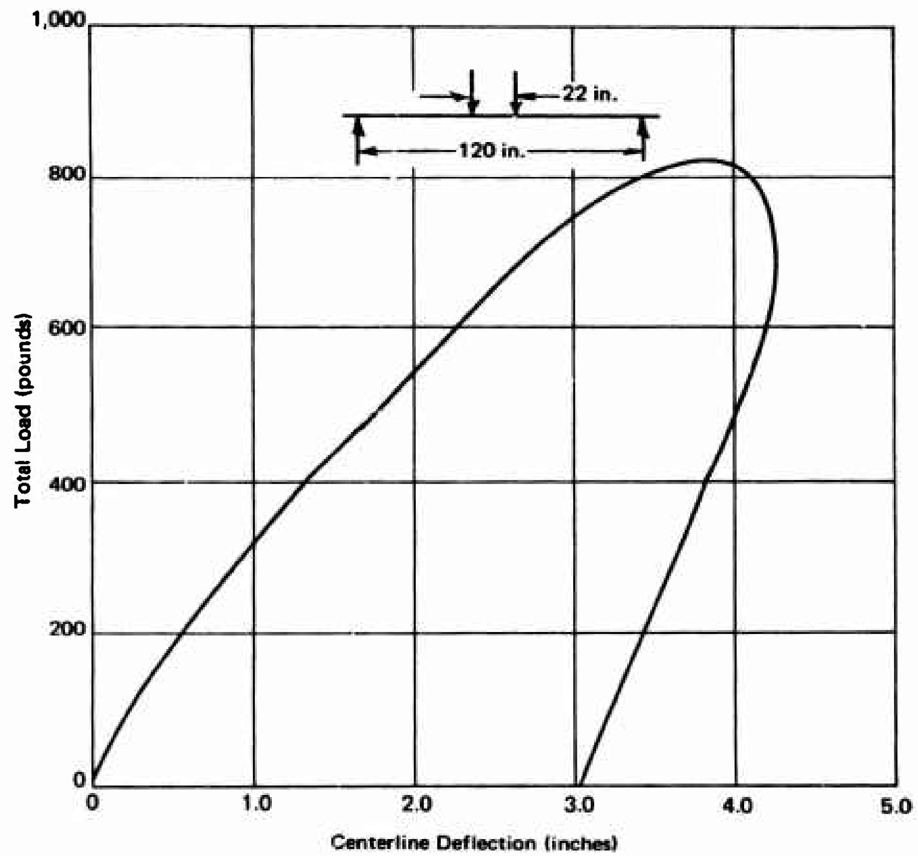


Figure B-7. Load—deflection curve, Beam 5, 106-mm ammunition boxes.

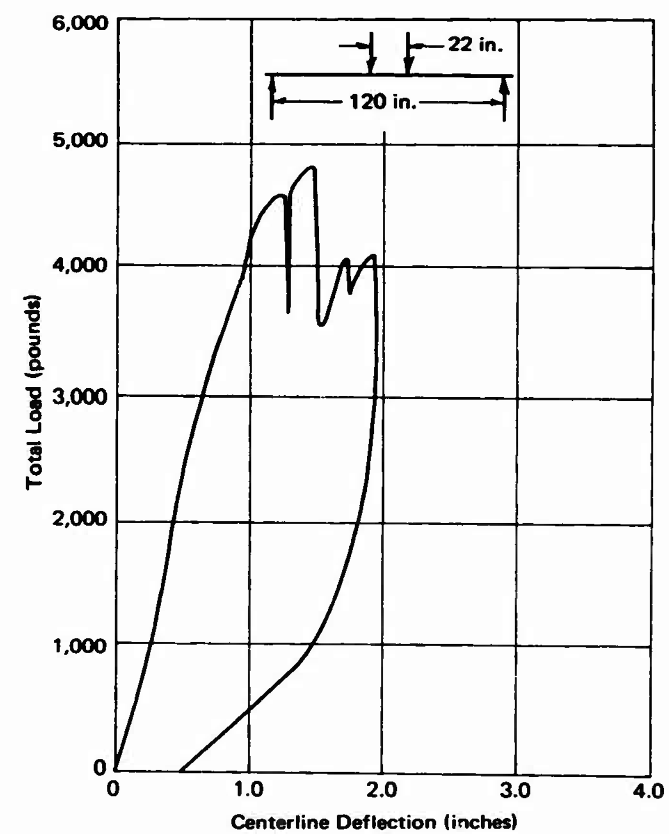


Figure B-8. Load—deflection curve, Beam 1-4, 106-mm ammunition boxes.

Appendix C

WOOD DETERIORATION STUDY

BEAM TESTS

To evaluate the loss of strength of beams from deterioration on exposure to the environment, beams of type 1, Appendix A, were built from 81-mm ammunition boxes and buried in the ground at Port Hueneme, California, to accelerate deterioration (Figure C-1). The test area was watered at least once each week. Some of the beams had been constructed from boxes treated with wood preservative. The treatment procedure consisted of dipping the open boxes for a period of 3 minutes in a tank filled with a copper naphthenate solution containing 2% copper metal (Figure C-2). The boxes were then allowed to drain dry. Several beams were tested initially. After various periods of time, beams were dug up and tested in flexure with the same procedure given in Appendix A. A two-point loading was used on a span length of 5 feet. The results of the tests are given in Figure C-3. Results of these tests indicate the loss of strength is gradual and after several months is not of major significance. Since this is an accelerated test, under actual field conditions the time in service would be several times that shown in Figure C-3. The loss of strength of a beam in an actual bunker would be about 10% after 3 months and 15% after 6 months. This is within acceptable limits.

BUNKER TEST OBSERVATIONS

A bunker was constructed using 106-mm ammunition boxes (Appendix E). Two of the four walls of the bunker and half of the overhead beams were made from treated boxes. The bunker was wet down at least once each week and observed for 4 months. Periodic visual inspection of the bunker did not reveal any significant deterioration either in the untreated wood or in the treated wood.

Figure C-1. Beams being buried for deterioration tests.

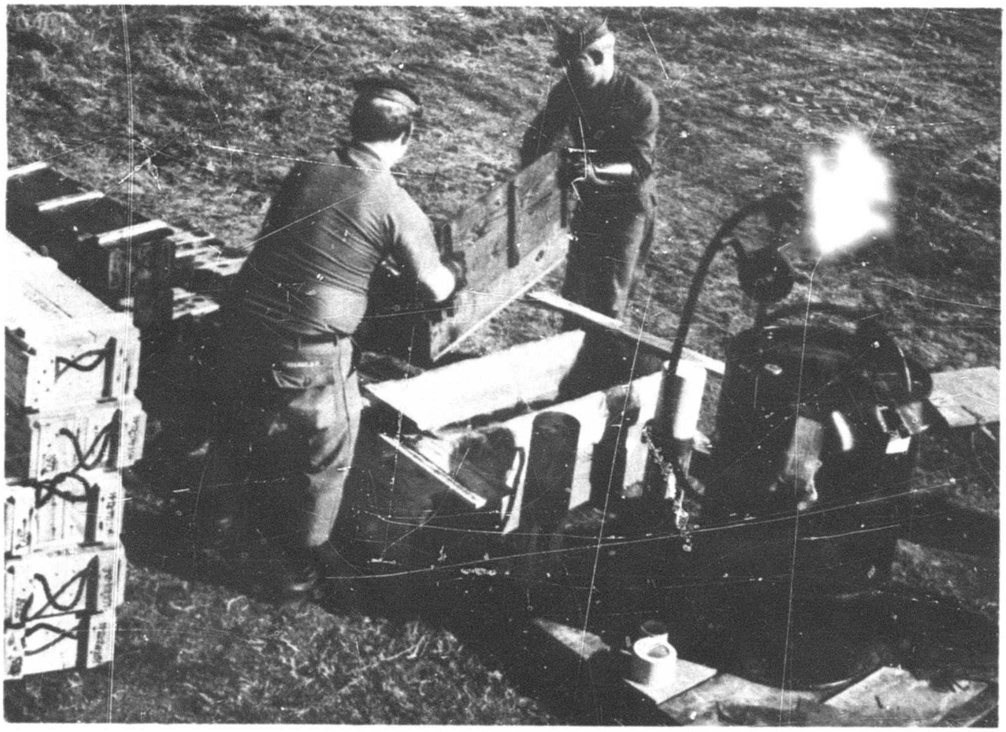


Figure C-2. Treatment with wood preservative.

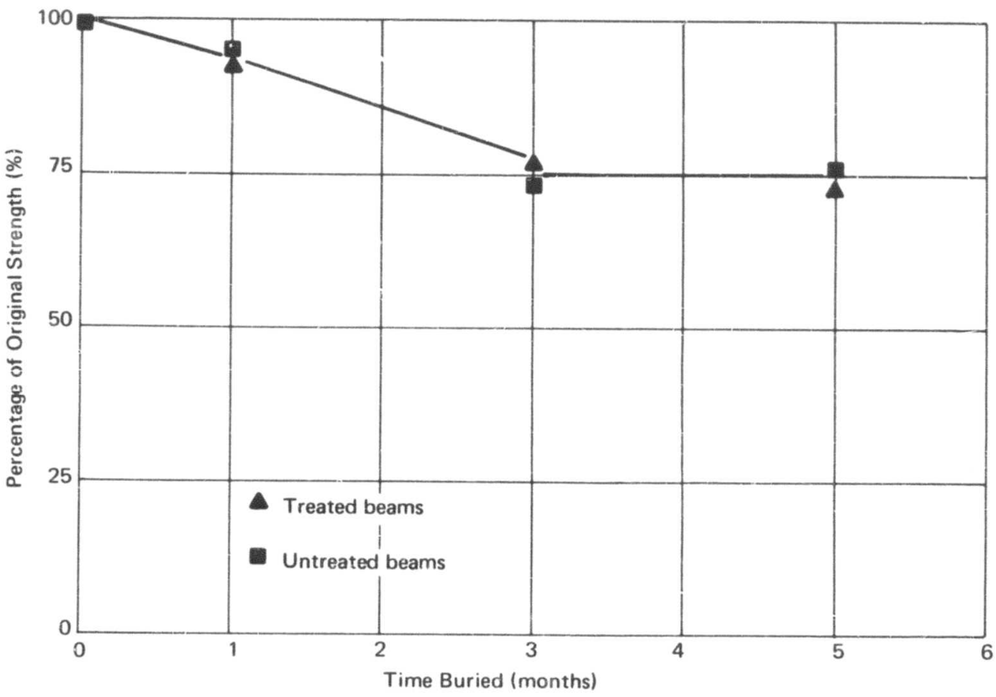


Figure C-3. Loss of beam strength through deterioration.

Appendix D

SOIL SLOPE DATA FOR FOXHOLE COVERS

by J. B. Forrest

FOXHOLE COVER CONSTRUCTION

Ammunition boxes can be joined to form beams capable of acting as foxhole covers. Two different types of beams tested can carry a soil surcharge 2 feet thick over unsupported lengths of 7 and 10 feet, respectively, while providing a factor of safety of approximately 2.0. This appendix is a guide to the allowable dimensions of foxholes to be covered with box beams.

To simplify the design, the number of involved variables was reduced as much as possible. The size of the foxhole is controlled by three parameters: the top width (**W**), the maximum depth (**D**), and the angle of side slope (β) (Figure D-1). The length of the beams is controlled by the top width (**W**) and the amount of overlap (**ΔL**) which provides bearing support for the roof.

By fixing the depth (**D**), the top width (**W**), and the depth of soil surcharge (**T**), it is possible to express the required angle of side slope (β) and beam bearing length (**ΔL**) as functions of the soil strength indices. Initially **W** was assumed to be 10 feet, and a correction for the 7-foot length is incorporated later. The depth of soil placed over the beam is assumed to be 2 feet, and the maximum foxhole depth is assumed as 4 feet.

The permissible angle of side slope depends solely upon slope stability considerations. Slope stability theory also controls the required beam bearing length, **ΔL**.

In order to incorporate the required beam bearing lengths into the analysis of the slope, the surcharge load placed over the beam and transmitted through the bearing is equated to an equivalent increase in height of slope. (Such an approach is probably somewhat conservative, since the surcharge load has a limited area of application.) For example, assuming **ΔL** to be 1.0 foot at each end of a beam spanning a 10-foot foxhole, then the surcharge load of thickness **T**, which actually extends over a 12-foot length, is concentrated over only a 2-foot length of bearing area. This results in an equivalent additional slope height of (12/2)**T** = 6**T**. This is added to the foxhole height of 4 feet, giving a total design height, **H**, of 4 + 6**T**.

One of the major problems in building any structure in soil is the evaluation or recognition of the soil characteristics. For the purposes described herein, any required soil tests must be minimal, so the soil will be classified only very roughly by appearance. Briefly, the soil may be observed to fall within one of three groups:

1. Granular, noncohesive soils—clean soils which do not stick together, such as sands or gravels. (Unified classification may be GW, GP, SE, or SP.)

2. Clays and clay soils—soils which exhibit tensile strength or which stick together and feel smooth or greasy to the touch; very little sand or particles large enough to be visible to the naked eye. (Unified classification may be CL, CH, ML, or MH.)

3. Cemented granular soils—soils composed primarily of particles visible to the naked eye but which stick together, requiring some effort to separate them. (Unified classification may be GC, GM, SC, or SM.)

An additional group of soils is that composed of largely organic matter, which is usually black, has a strong odor, and has an abundance of plant material incorporated in it. These soils are generally very soft and mushy and are associated with high water tables, which would preclude the use of foxholes discussed herein. Therefore, they will not be included in this development.

Since the foxhole design parameters can be expected to vary with the three basically different types of soil referred to above, each soil must be considered separately.

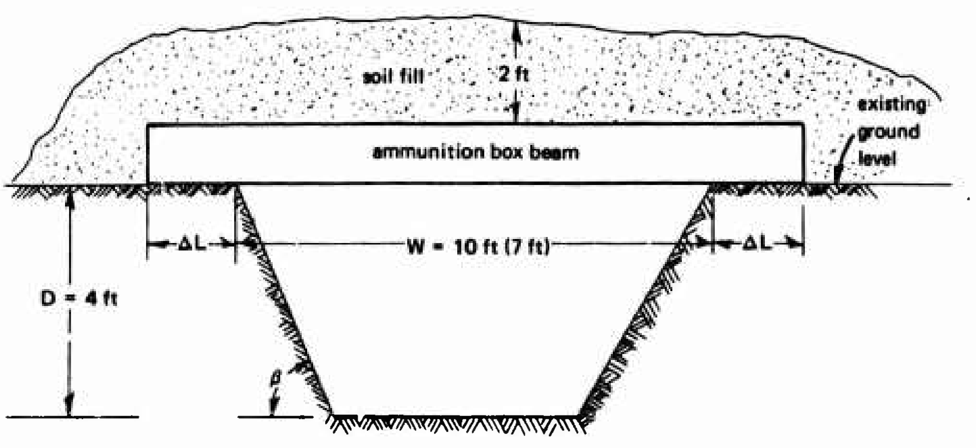


Figure D-1. Foxhole cover configuration.

GRANULAR, NONCOHESIVE SOILS

Such soils may not be considered stable when arranged with slopes steeper than the angle of internal friction which is equal to the angle of repose (that angle which will form when the soil is poured gently into a conical pile). When arranged at a slope flatter than the angle of repose, there is no limit as to the permissible height of the slope. The angle of internal friction for a granular material usually varies from about 28 degrees (approximately 1:2, vertical to horizontal) to 45 degrees (approximately 1:1 slope), depending upon density. Damp sands may have an apparent cohesion or stickiness which permits the sand to stand at slopes steeper than the angle of repose, but this cohesion is lost following drying and should not be depended upon.

Recommendation. Clean granular materials should not be expected to remain at a slope, β, greater than about 30 degrees (1:1.75, vertical to horizontal). The length of beam bearing, ΔL, for this type of soil should be at least 6 inches.

CLAYS AND CLAY SOILS

The data used for design in this type of soil are taken from Figure 7-1 of Navy Bureau of Yards and Docks "Design Manual—Soil Mechanics, Foundations, and Earth Structures,"[7] which considers the soil only in terms of its shear strength, **C**. For the type of application discussed herein, "Base circles" (circular failure surfaces intersecting the soil below the toe of the slope) as denoted in Figure 7-1 are highly unlikely, and slope circles (failure circles intersecting the slope) are apt to be conservative. Therefore, to get an approximate relationship for slope angle in terms of the other soil characteristics, the curve for stability number, N_o, versus slope angle, β, in degrees, (in Figure 7-1) for toe circles only was approximated in the form $N_o = 7.83(1 - 0.00567\beta)$. This relationship holds in Figure 7-1 over the range of interest of β.

Combining this relationship with the relationship*

$$F_s = N_o \frac{C}{\gamma H}$$

* From Figure 7-1.

where F_s = factor of safety against failure

H = unsupported height of slope

γ = average density of soil

C = soil shear strength

leads to

$$N_o = \frac{F_s \gamma H}{C} = 7.83(1 - 0.00567\beta)$$

The height, **H**, including the equivalent height caused by the surcharge, **T**, becomes: $H = 4 + \{1 + [(10 + 2\Delta L)/\Delta L]\}\, T$

It is necessary, when dealing with slopes in very soft soils, to use minimum factors of safety to prevent excessively flat slopes, which would preclude the use of foxhole covers. With more competent soils, the factor of safety is generally increased. By dropping the 4 in the expression for **H**, the factor of safety will be seen to be almost unaffected at small ΔL (competent soils) and reduced at large ΔL (poor quality soils). Since this treatment is necessary for functionality, the expression used for **H** will be $[1 + (5/\Delta L)]\, T$, and a larger factor of safety than is usually recommended (2 instead of 1.5) is incorporated into the design. This factor of safety is automatically reduced for cases of weak soils, as is desirable, but is prevented from dropping below a value where failure could occur.

Using the previous reasoning and assuming

$$\gamma = 115 \qquad F_s = 2.0 \qquad T = 2.0 \text{ feet}$$

one arrives at

$$N_o = \frac{2.0(115)\left(1 + \frac{5}{\Delta L}\right)}{C} = 7.83(1 - 0.00567\beta)$$

or

$$\frac{(1 - 0.00567\beta)\, C}{1 + \frac{5}{\Delta L}} = 59$$

This relationship is plotted in Figure D-2 for three values of β: 90, 60, and 30 degrees.

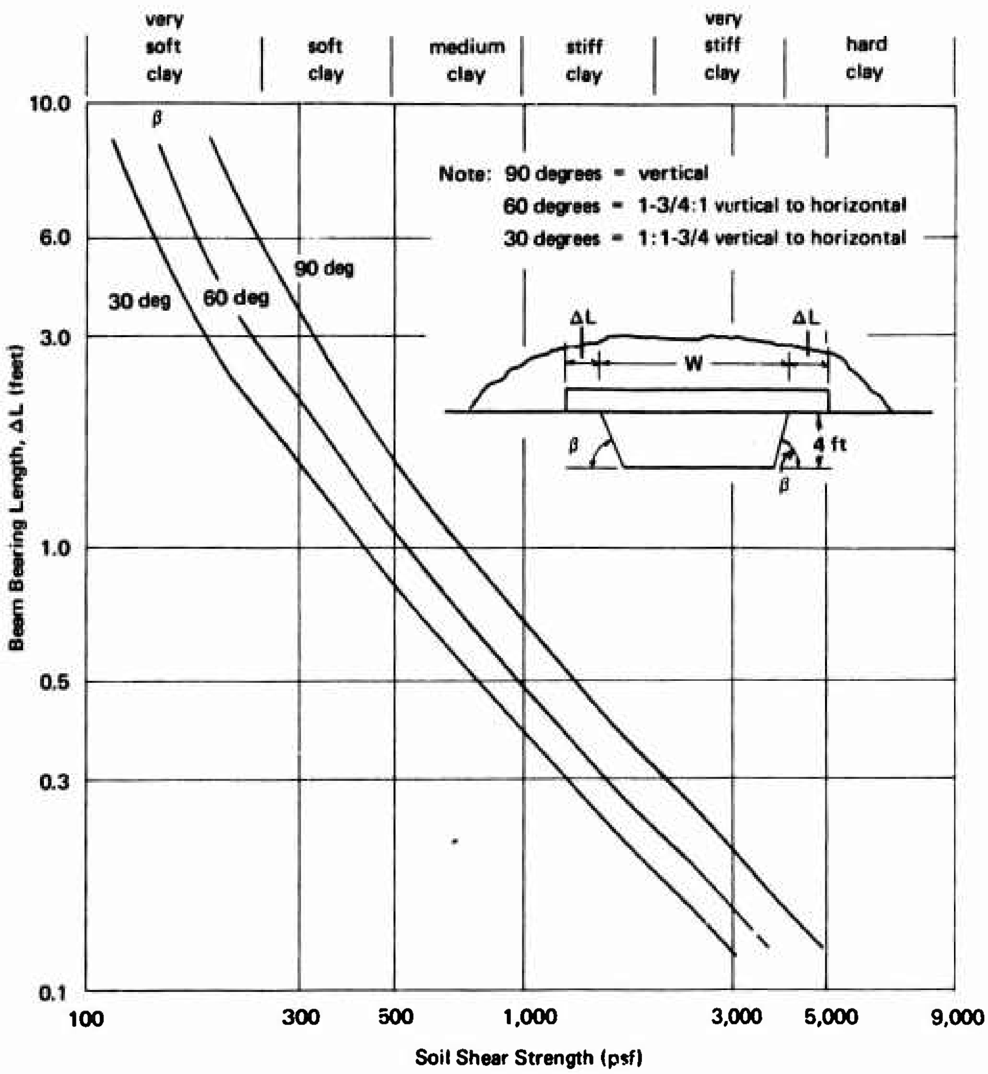


Figure D-2. Beam bearing length versus soil shear strength for cohesive soils (clayey) with no sand or gravel.

Recommendation. Enter into Figure D-2 with a specific shear strength or soil classification at the abscissa and using the curve of side slope desired, determine the required value of bearing length, **ΔL**. It is recommended for clays that **ΔL** should not be less than 6 inches.

Since the exact shear strengths of the soils encountered will generally be unknown, Figure D-2 also defines the clays in somewhat qualitative terms from very soft to hard. A rule of thumb in identifying the various soil competencies is as follows:

very soft—can be penetrated by fist
soft—can be penetrated by thumb
medium—can be indented by thumb
stiff—can be scratched with thumbnail
very stiff—difficult to indent with thumbnail

The foregoing was derived for a 10-foot unsupported span. For a 7-foot unsupported span, it is conservative to reduce the required **ΔL** for a specific soil type and side slope by 25%.

It must be noted that the foregoing assumes no water flowing into the foxhole, since if the foxhole were located below the water table it would be of little value. Since very soft cohesive soils are generally associated with high water tables, it is expected that the presence of such soils would indicate the unfeasibility of foxholes such as those discussed here.

CEMENTED GRANULAR SOILS

The data used for design in this type of soil were taken from Figure 7-4 of Reference 7, which considers soil having both cohesion, **C**, and frictional resistance, ϕ.

The curves of Figure 7-4, which relate slope angle, β, to stability number, N_{cf}, are approximated by the expression

$$N_{cf} = 17(1 - 0.00667\beta)\sqrt{\frac{\lambda_{c\phi}}{3}}$$

where $\lambda_{c\phi} = \lambda H \tan\phi / C$

$F_s = N_{cf}\, C/\gamma H$

γ = soil density

H = unsupported slope height (including equivalent)

ϕ = angle of internal friction of the soil

C = cohesion or shear strength of soil

Substituting the expressions for $\lambda_{c\phi}$ and N_{cf},

$$\frac{\gamma H F_s}{C} = \frac{17}{\sqrt{3}}(1 - 0.00667\beta)\sqrt{\frac{\gamma H \tan\phi}{C}}$$

substituting T = 2 feet

γ = 120 pcf

F_s = 1.5

H = $[1 + (5/\Delta L)]\ 2 + 4$

and simplifying

$$\sqrt{C \tan\phi} = \frac{\sqrt{\left(1 + \frac{5}{\Delta L}\right)^2 + 4}}{0.595(1 - 0.00667\beta)}$$

This relationship is plotted in Figure D-3 for two values of β; 90 and 60 degrees. The value of ϕ was arbitrarily assumed at 32 degrees, corresponding to a medium dense sand; therefore, a slope of 32 degrees would be expected to be stable for any height (or surcharge).

Recommendation. Enter Figure D-3 with a specific type of cemented granular soil and, using the curve of side slope desired, determine the required value of bearing length, ΔL. It is recommended that ΔL be not less than 6 inches. Using Figure 7-4 of Reference 7 to check specific cases solved with Figure D-3 will show factors of safety in the vicinity of 1.4 to 1.5.

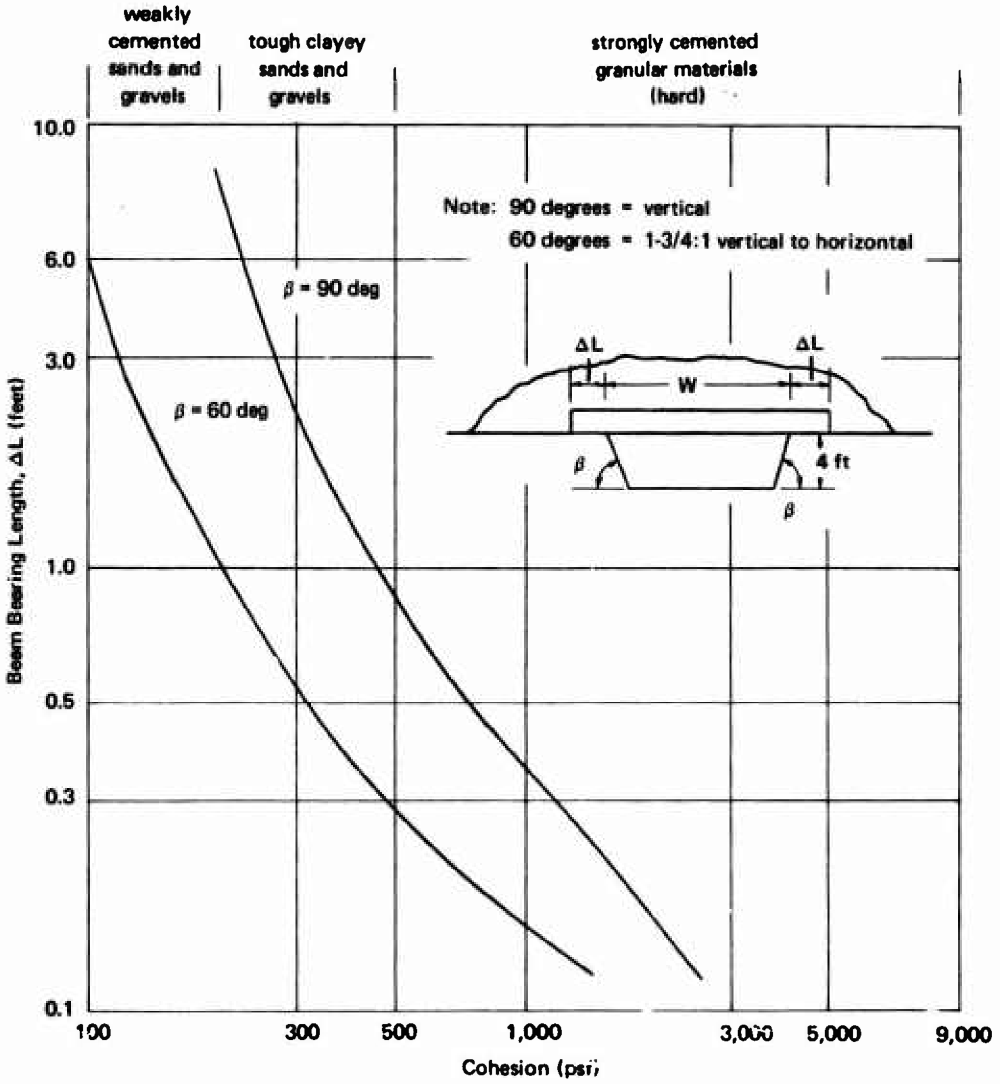


Figure D-3. Beam bearing length versus cohesion for cemented granular soil and mixed soil (assume medium dense, ϕ = 32 degrees).

The exact cohesive values of the soils encountered will generally be unknown; therefore Figure D-3 also attempts to define the soils in somewhat qualitative terms, going from weakly cemented to cemented materials. Weakly cemented sand and gravel would be defined as those which can be raveled from a slope by scraping with a sharp object or those which can be broken apart with the hands without too much difficulty. Cemented granular materials cannot be readily broken apart with the hands.

As with the cohesive soil treatment, cases for an unsupported beam length of 7 feet can be handled by reducing the required ΔL for a specific soil type and slope by 25%.

Again it must be noted the foregoing does not hold for cases of high water table, wherein unlined foxholes would be of limited value.

Appendix E

BUNKER CONSTRUCTION WITH 106-mm AMMUNITION BOXES

Figures E-1 through E-11 show the construction sequence of a bunker built from 106-mm ammunition boxes at Port Hueneme, California. Plans for this bunker are given in Figure 7. The total construction time was 160 man-hours, not including the excavation of the hole. About 75 pounds of 10-penny nails were required. The cleats on the lids of the boxes forming the walls were not removed; subsequent tests, described in Appendix F, show the cleats *must* be removed to prevent fragments from entering into the bunker through the space between boxes. Since this was an experimental test, the soil making up the overhead protection was placed in sandbags to calculate the weight more accurately. In an actual field bunker this would not be required. Boxes could be filled and stacked on top of the beams.

Numerous bench marks were established and the elevations of various points were monitored over a 3-month period to evaluate creep under permanent load. Results of the observation did not indicate any significant settlement of the walls. The creep deflection of the beams with time is shown in Figure E-12.

Figure E-1. Filling ammunition box with soil.

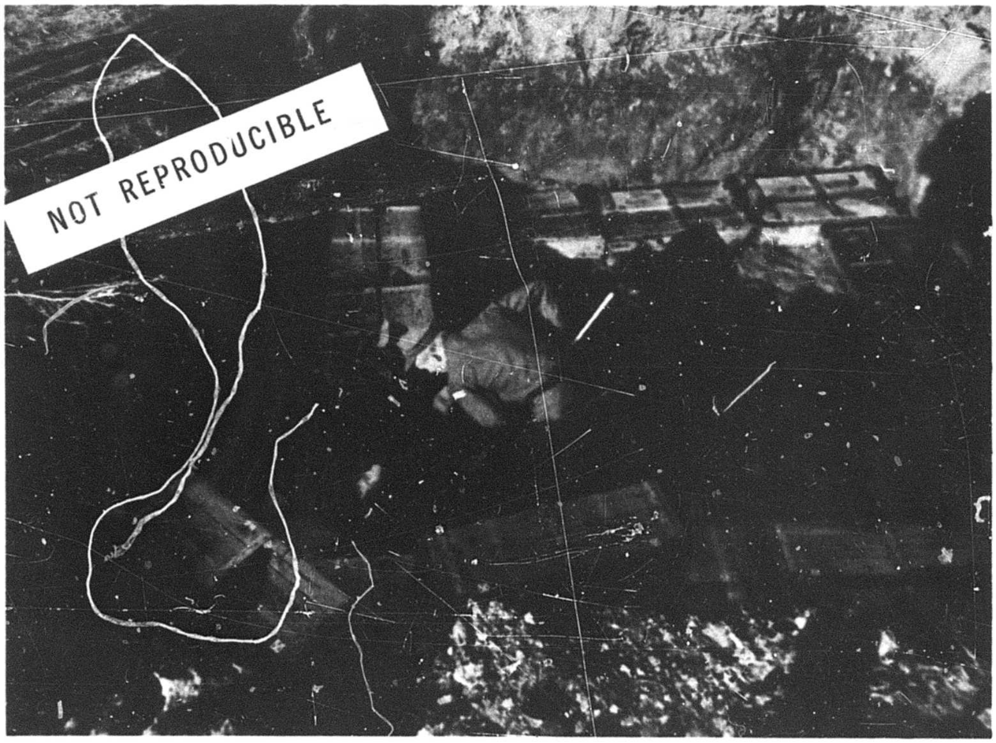


Figure E-2. Leveling ground for first layer of boxes.

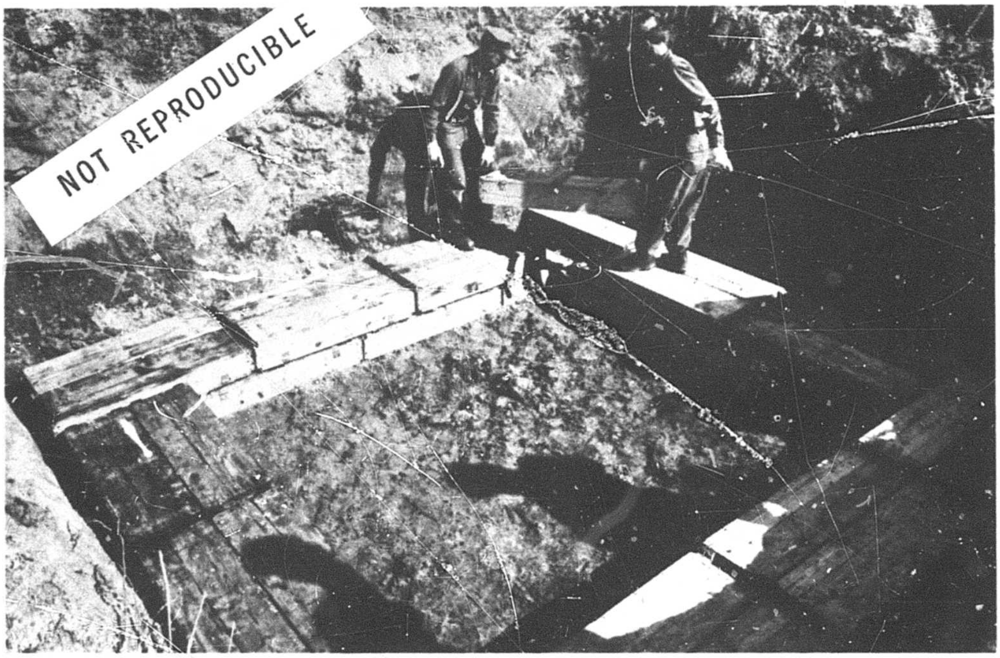


Figure E-3. Placing second layer of boxes.

Figure E-4. Bunker wall construction.

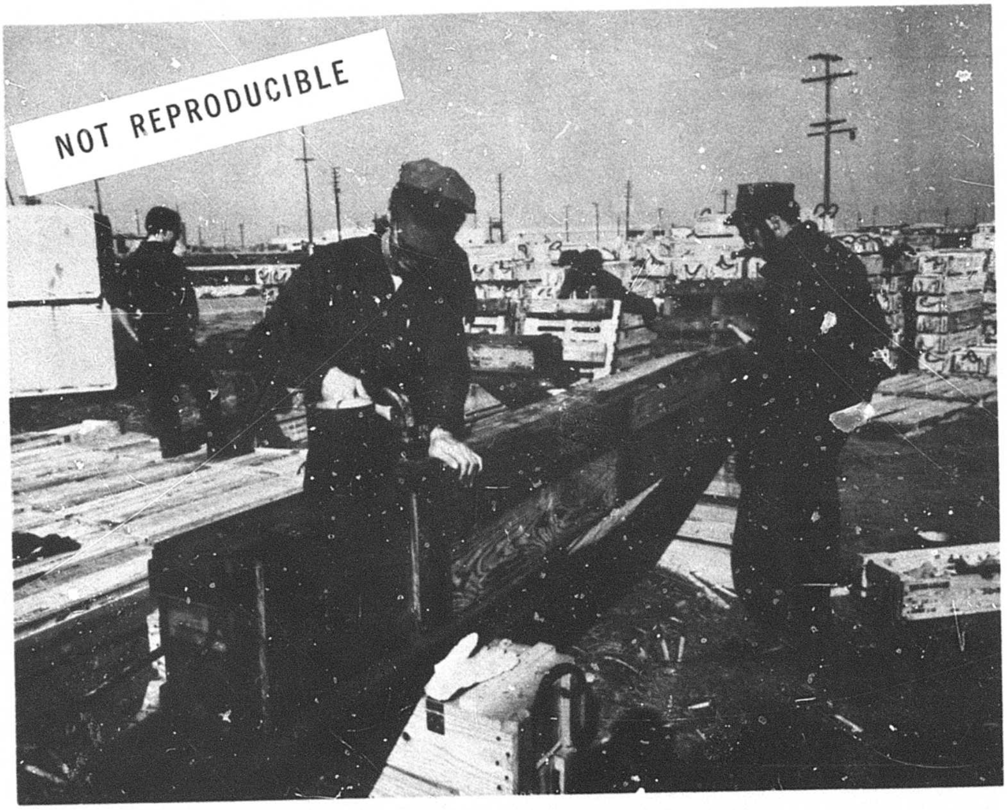


Figure E-5. Overhead beam construction.

Figure E-6. Placing overhead beams in position.

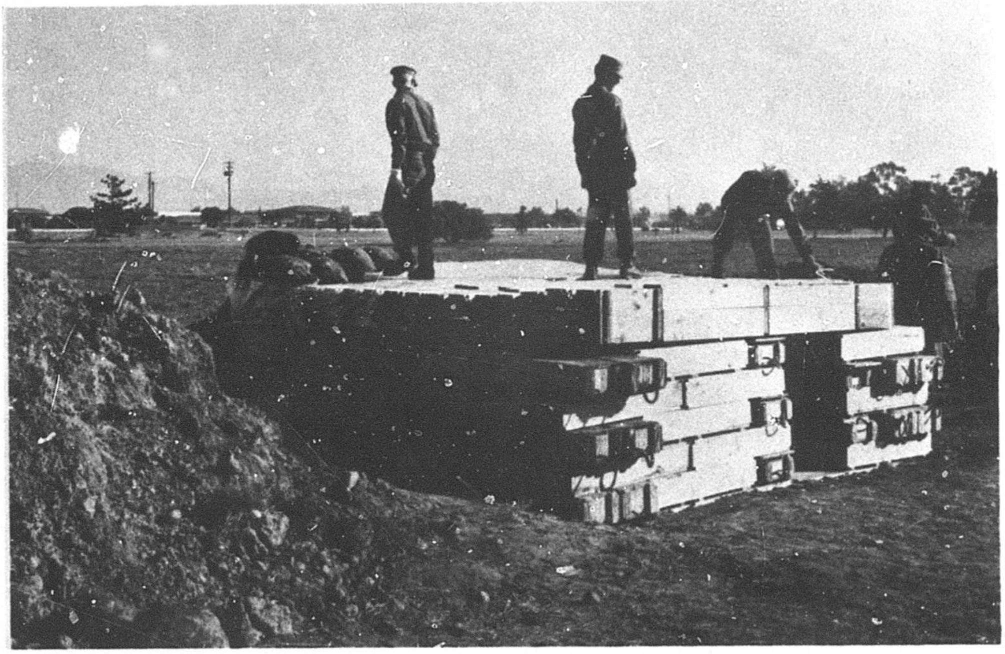


Figure E-7. Placing sandbags on top of beams.

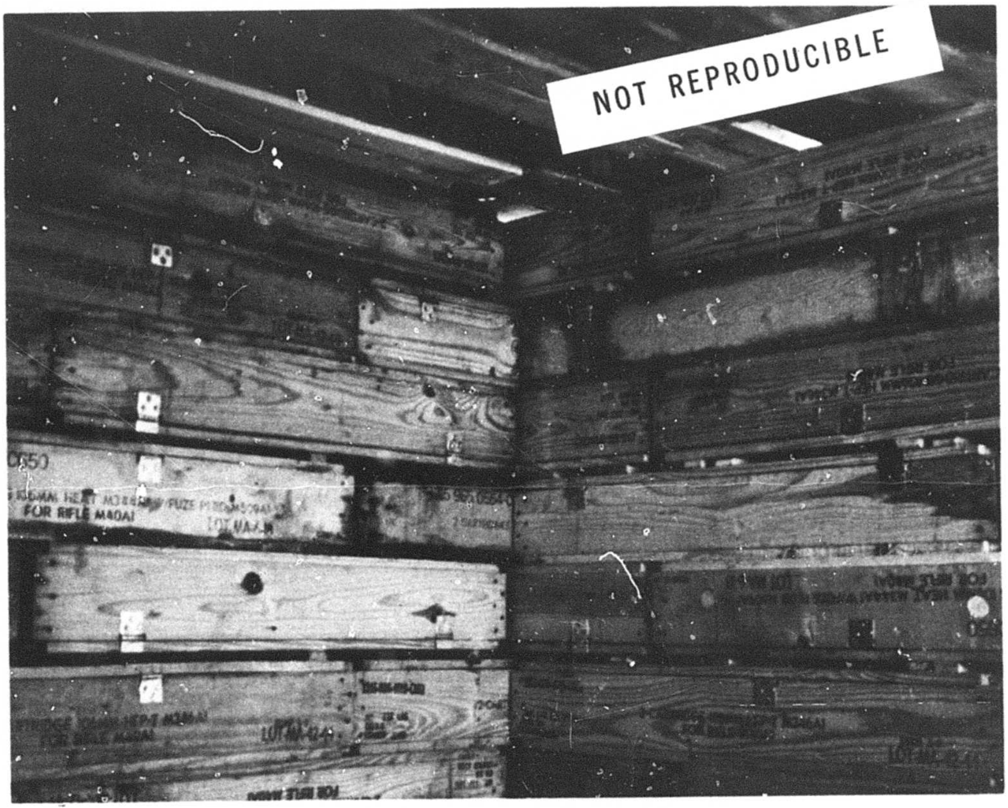


Figure E-8. Interior of bunker.

Figure E-9. Front view of bunker.

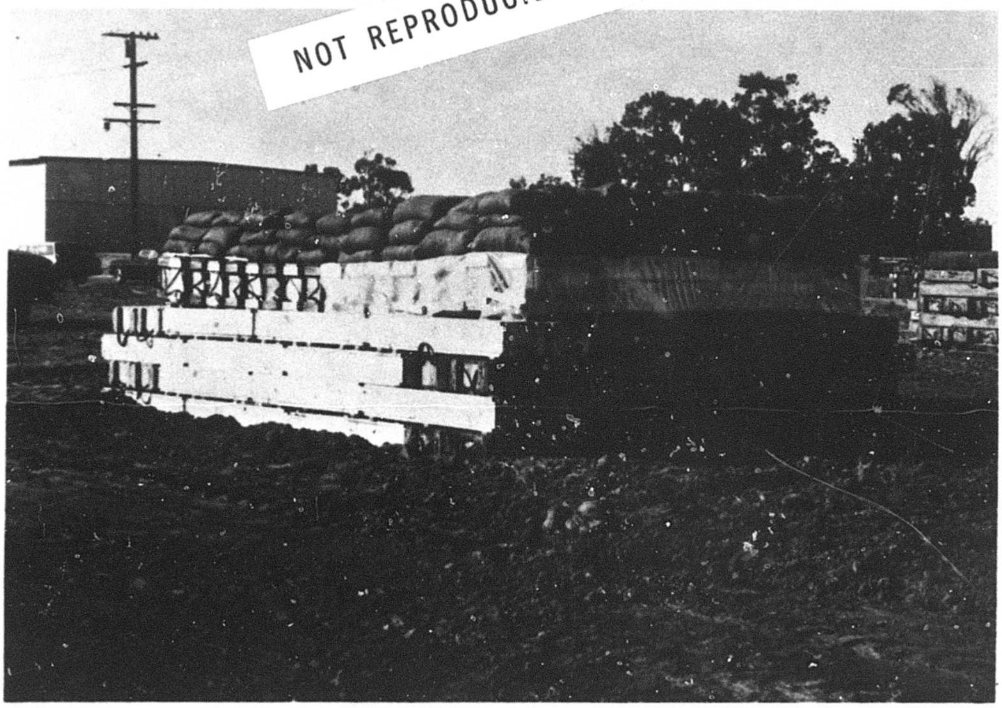


Figure E-10. Oblique view of bunker.

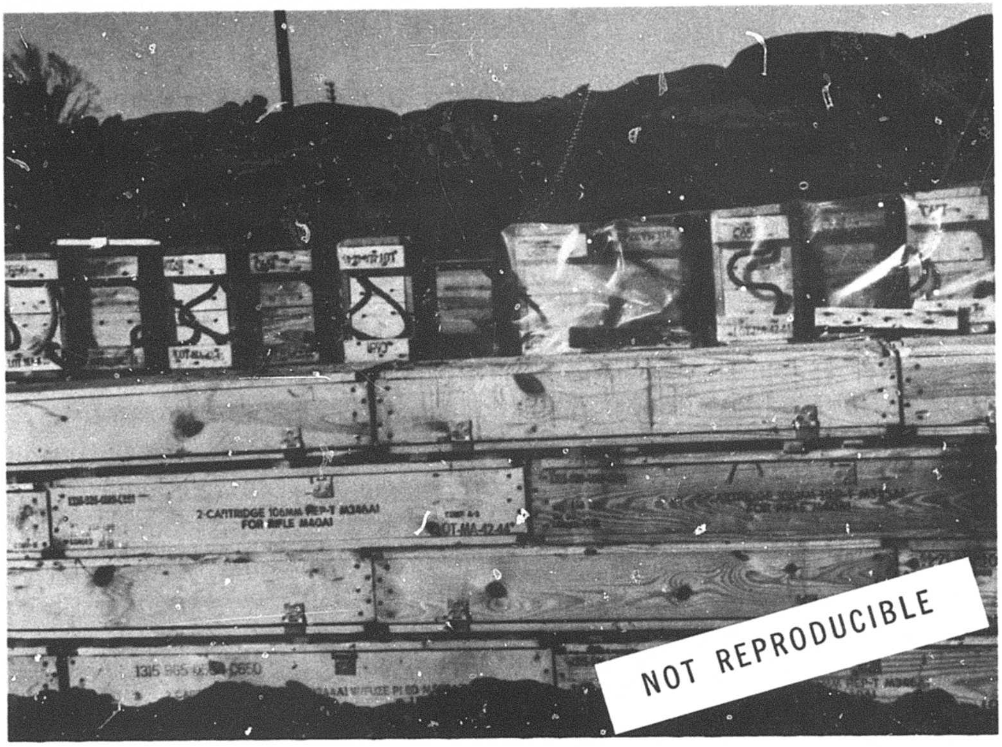


Figure E-11. Side view of bunker.

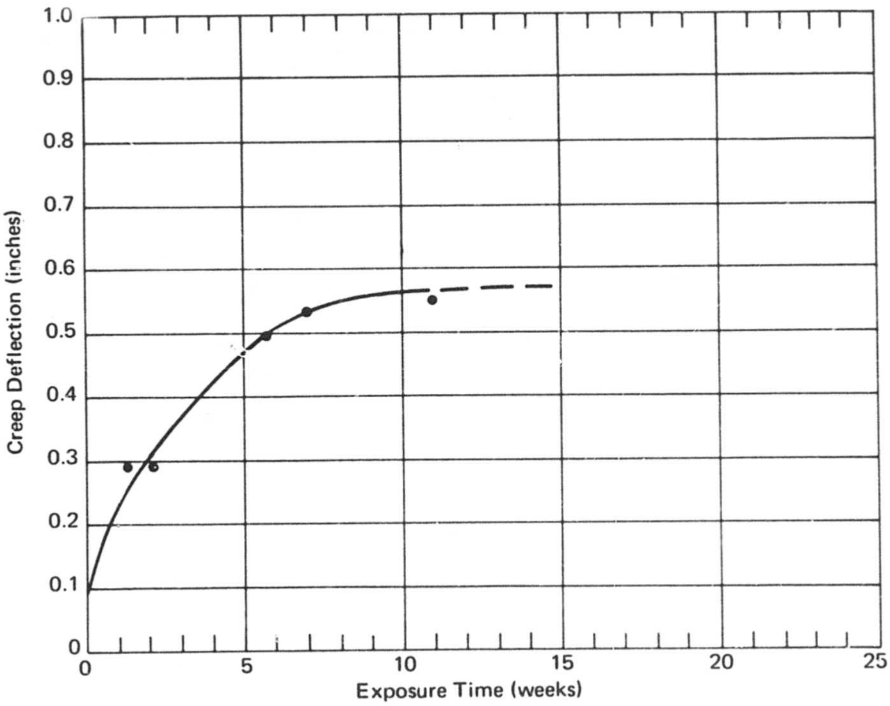


Figure E-12. Creep deflection of beams exposed to environment.

Appendix F

EVALUATION OF BUNKER VULNERABILITY TO BLAST AND FRAGMENTATION

BUNKER CONSTRUCTION

A second bunker was constructed, at Camp Pendleton, California, with 106-mm ammunition boxes. The procedures for building this bunker were the same as those shown in Appendix E and in Figure 7 except that the bunker was built completely above ground. Figure F-1 shows the bunker construction. In addition to the bunker, two separate walls were constructed, one with sandbags and the other with soil-filled ammunition boxes. The walls, 2 feet thick, 4 feet high, and 10 feet long, represented the exposed aboveground portion of a typical partially buried bunker (Figure F-2).

TEST PROCEDURE

To evaluate the ability of wooden ammunition boxes to protect against fragments, various munitions were placed at distances from the test walls and the bunker and exploded. Three basic rounds were used: 81-mm mortar, 105-mm artillery, and 155-mm artillery (Figures F-3, F-4, and F-5, respectively) The fuzes from these rounds were removed and a small amount of Composition C4 explosive was placed in the fuze well. Blasting caps were inserted into the fuze well, and the round was electrically detonated in place. All rounds were oriented vertically, nose down, in contact with the ground. Fragments were observed by penetrations through witness sheets made of 6-mil polyethelene plastic. After each test, repairs to the test walls were made, and new witness sheets were installed. Rounds were fired at adjacent sides of the bunker, and repairs were not made to the bunker. Additionally, 50 rounds of 50-caliber machine gun ammunition were fired against the test box wall (Figure F-6).

TEST RESULTS

The test plan and a summary of the results are given in Table F-1. The observed number of penetrations and extent of damage were used to determine the curves in Figure 10.

Table F-1. Results of Blast and Fragmentation Tests

Weapon	Distance (ft)	No. of Penetrations	Remarks
Ammunition Box Wall			
50-caliber machine gun (50 rounds)	150.0	20	hole formed
81-mm mortar	10.0	0	
81-mm mortar	6.0	0	
81-mm mortar	2.0	0	
105-mm artillery	13.2	2	
105-mm artillery	8.2	4	moderate damage to exterior of wall
105-mm artillery	2.7	8	
155-mm artillery	30.0	2	
155-mm artillery	19.2	4	
155-mm artillery	11.5	10	collapsed wall
Sandbag Wall			
81-mm mortar	10.0	0	
105-mm artillery	12.0	0	
155-mm artillery	20.0	1	wall blown down
Ammunition Box Bunker			
81-mm mortar	10.0	0	
81-mm mortar	6.0	0	
81-mm mortar	4.0	0	
105-mm artillery	18.0	0	
105-mm artillery	12.0	1	
105-mm artillery	9.0	5	
155-mm artillery	20.0	2	
155-mm artillery	30.0	0	
81-mm mortar	2 feet above overhead sandbags	0	
81-mm mortar	in contact with overhead sandbags	0	

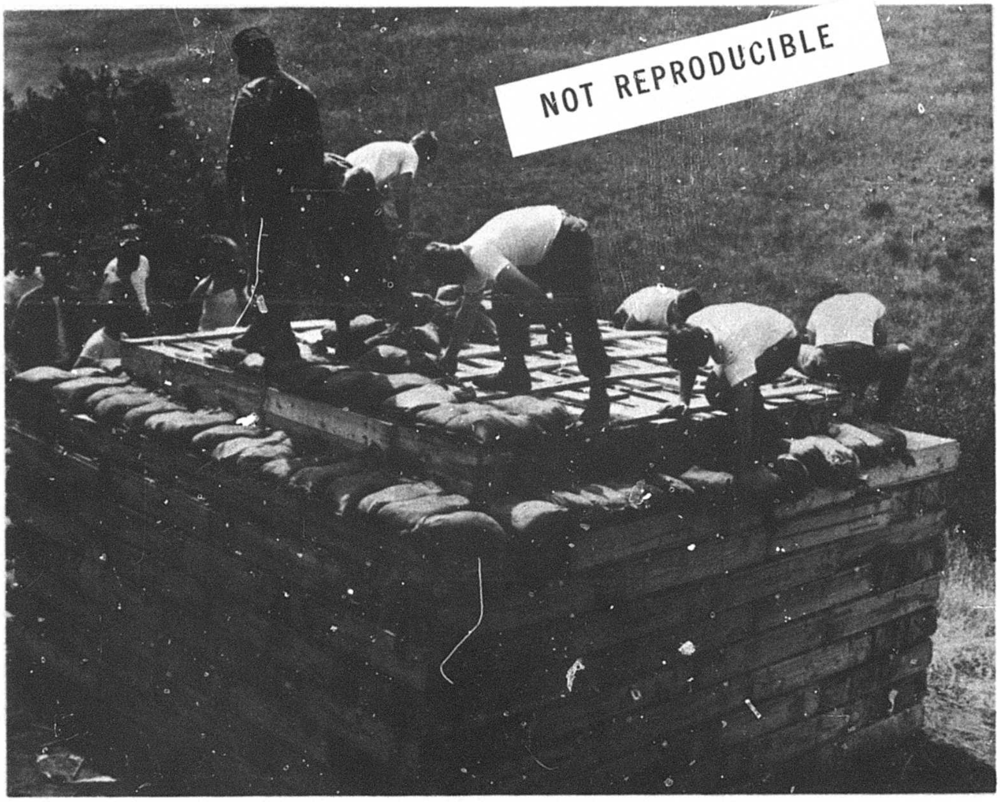


Figure F-1. Bunker construction at Camp Pendleton.

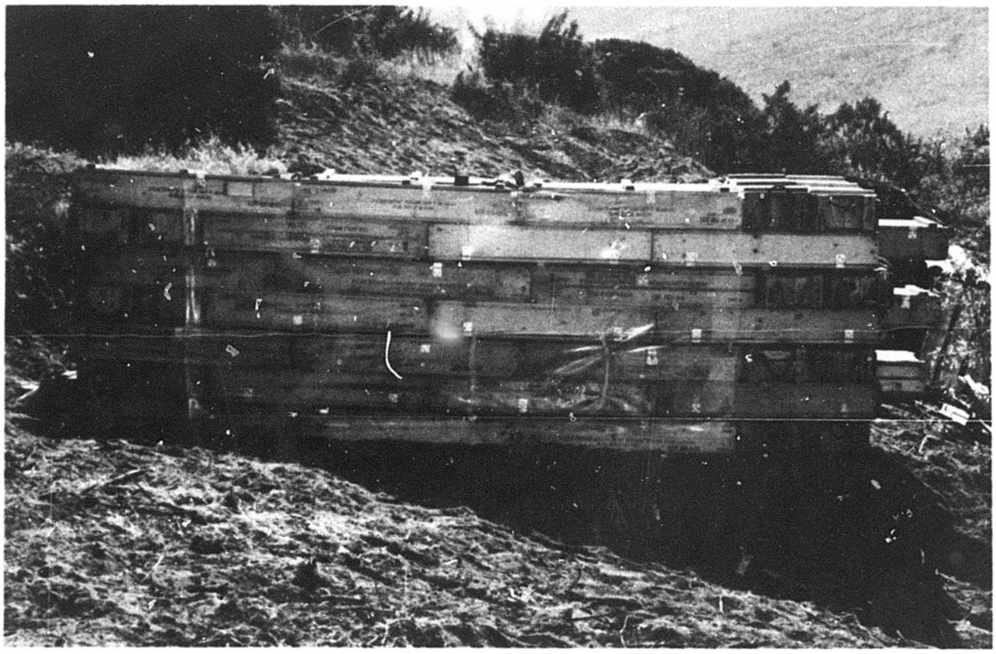


Figure F-2. Test wall simulating bunker.

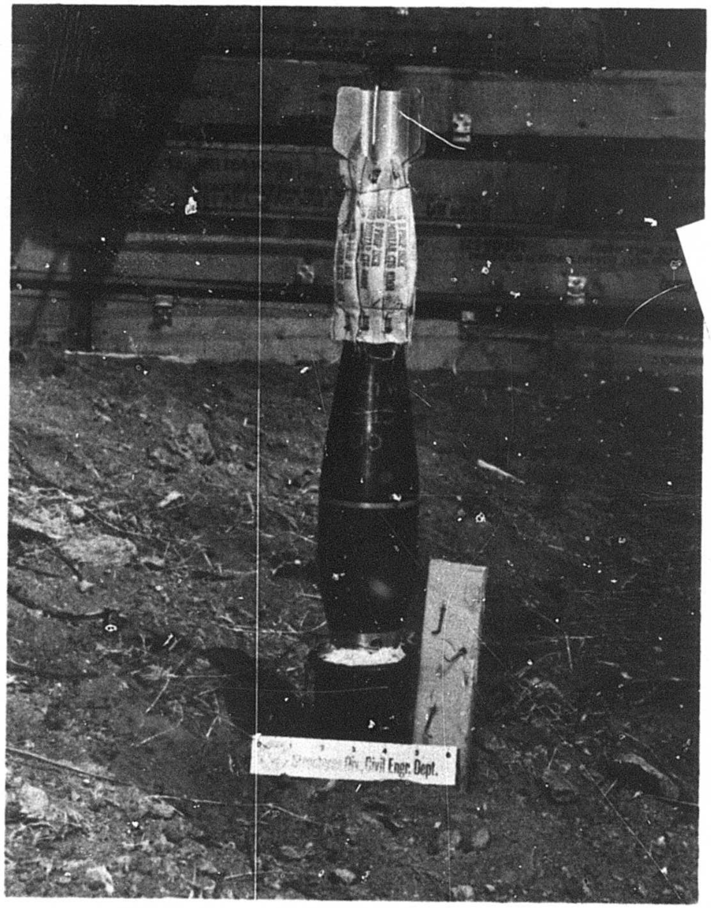


Figure F-3. Round of 81-mm mortar ammunition.

Figure F-4. Round of 105-mm artillery ammunition.

The cleats were not removed from the lids of the boxes used to construct the bunker and test wall, and this resulted in spaces between the boxes. The test showed that these spaces allowed fragments to enter into the bunker. To prevent this, *it is recommended that the cleats be removed.* Figure 10 does not consider penetrations between boxes permitted by the space from the cleats but rather assumes the cleats will be removed and that all penetrations will be through the boxes themselves.

The 2 feet of box wall thickness provides complete protection from the fragments of an 81-mm mortar at any separation distance. Complete protection from a 105-mm artillery round requires a separation distance of at least 18 feet; while complete protection from a 155-mm artillery round requires a separation distance of at least 25 feet. Collapse of the bunker can be expected to occur at a separation distance of about 4 feet from a 105-mm round and about 9 feet from a 155-mm round. Figures F-7 and F-8 are typical photographs showing more severe damage.

Two 81-mm mortar rounds were exploded on top of the bunker; one 2 feet above the overhead sandbags and the other in contact with the sandbags. In both cases no fragments penetrated into the bunker. The roof suffered damage consisting mainly of destroyed sandbags (Figure F-9). The beams directly beneath the exploding rounds had a permanent deflection of about 1 inch for the 81-mm mortar round placed 2 feet away and 3 inches for the 81-mm mortar round placed in contact with the sandbags (Figure F-10).

Figure F-5. Round of 155-mm artillery ammunition.

As noted in Table F-1, the sandbag walls appeared to be slightly more effective in stopping fragments than did the ammunition boxes. This is understandable, since a sandbag torn by a fragment tends to seal itself by the weight of soil above (Figure F-11), whereas a hole in a soil-filled ammunition box results in a loss of a portion of the soil through leakage. This fact is very significant when considering the protection required against direct fire from a 50-caliber machine gun. Although the amount

of soil present is sufficient to stop a single 50-caliber round, repeated fire causes a hole to form, resulting in loss of soil (Figures F-12 and F-13). Thus in effect the machine gun bores its way through the wall. This problem can be overcome by providing three layers of boxes in the exposed portion of the wall as described in the report.

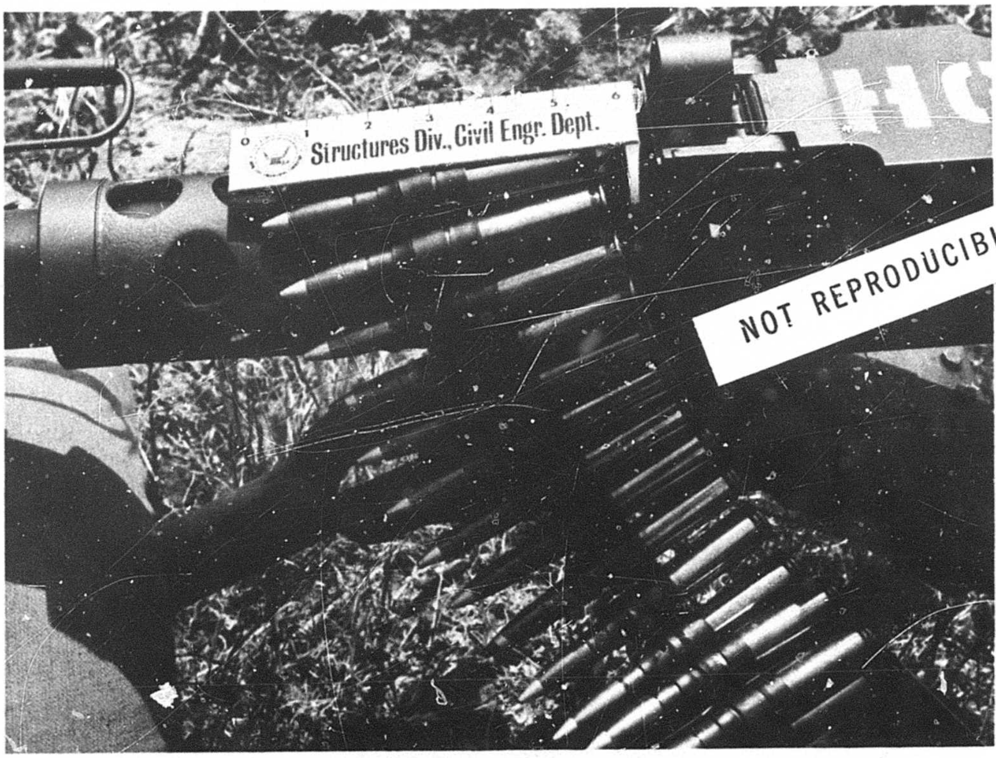


Figure F-6. Rounds of 50-caliber machine gun ammunition.

FRAGMENTATION DATA

Data supplied by the Naval Ordnance Laboratory, White Oak, Maryland, giving the predicted number and mass of the fragment distribution expected from 81-mm mortar rounds and 155-mm artillery rounds indicate a very large number of the fragments are extremely small.

Poncelet's equation of penetration is given as

$$z = \frac{P}{2gib} \ln\left[1 + \frac{b}{a}(V_o^2)\right]$$

where z = penetration (in.)

P = projectile weight per normal frontal area (psi)

V_o = striking velocity (fps)

g = 32.2 ft/sec^2

i = form factor, usually 1

b = constant (lb-sec^2/ft^2-in.^{2})

a = constant (psi)

From this equation, the depth of penetration is proportional to the projectile pressure (projectile weight per area). Considering an idealized representation of a sphere, the weight of the sphere increases as a function of radius cubed, while the area increases as a function of radius squared. Thus penetration, which is proportional to the ratio of weight per area, increases proportionally with a spherical projectile's radius. Additionally, small fragments are more affected by air drag than are larger fragments. This increased drag reduces the striking velocity of small particles. Thus small particles do not pose the same threat as do larger ones.

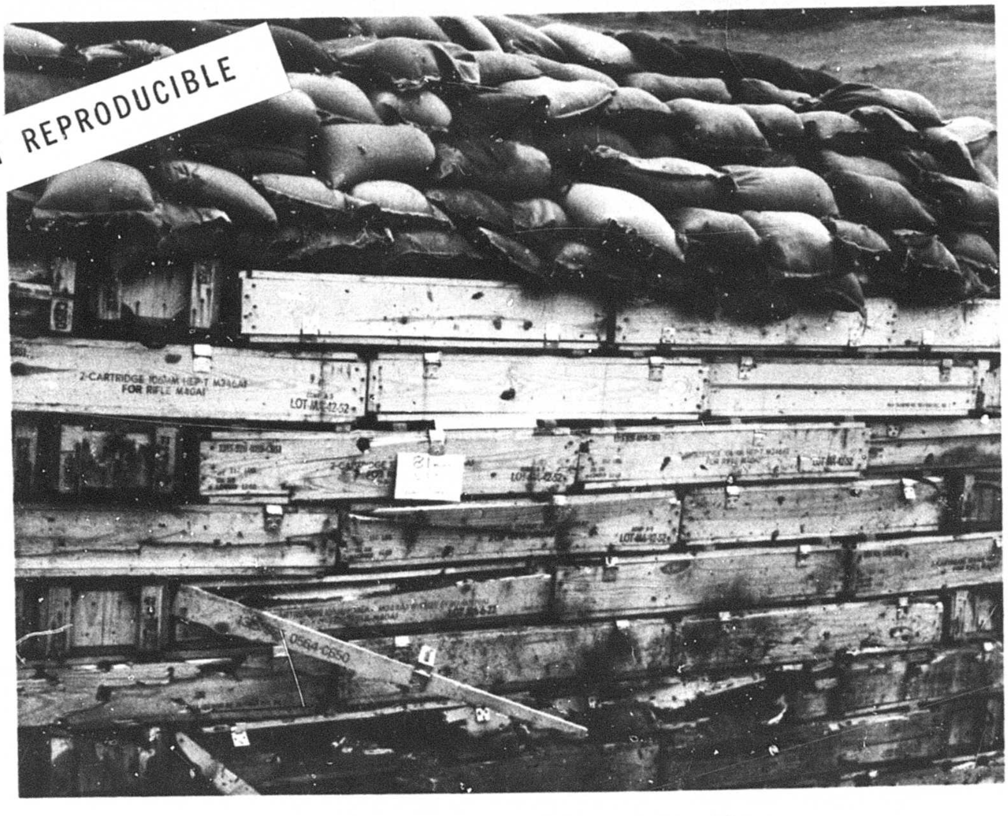


Figure F-7. Damage from 81-mm round at 4 feet.

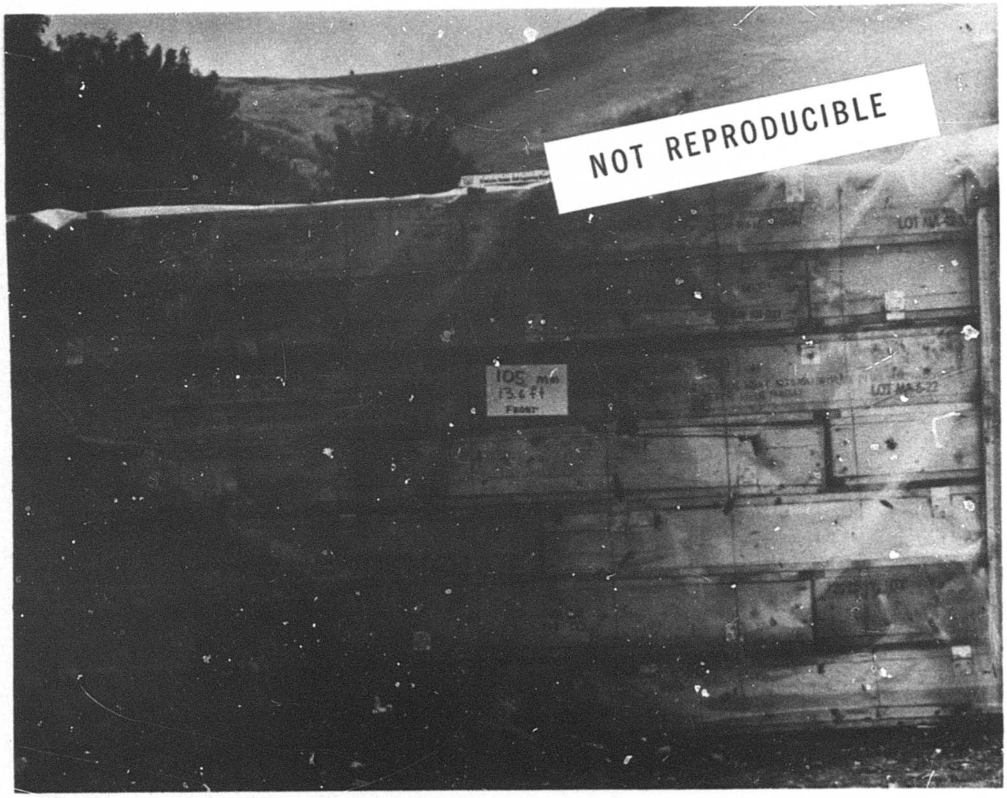


Figure F-8. Damage from 105-mm round at 13.6 feet.

Figure F-9. Damage from 81-mm round 2 feet above roof.

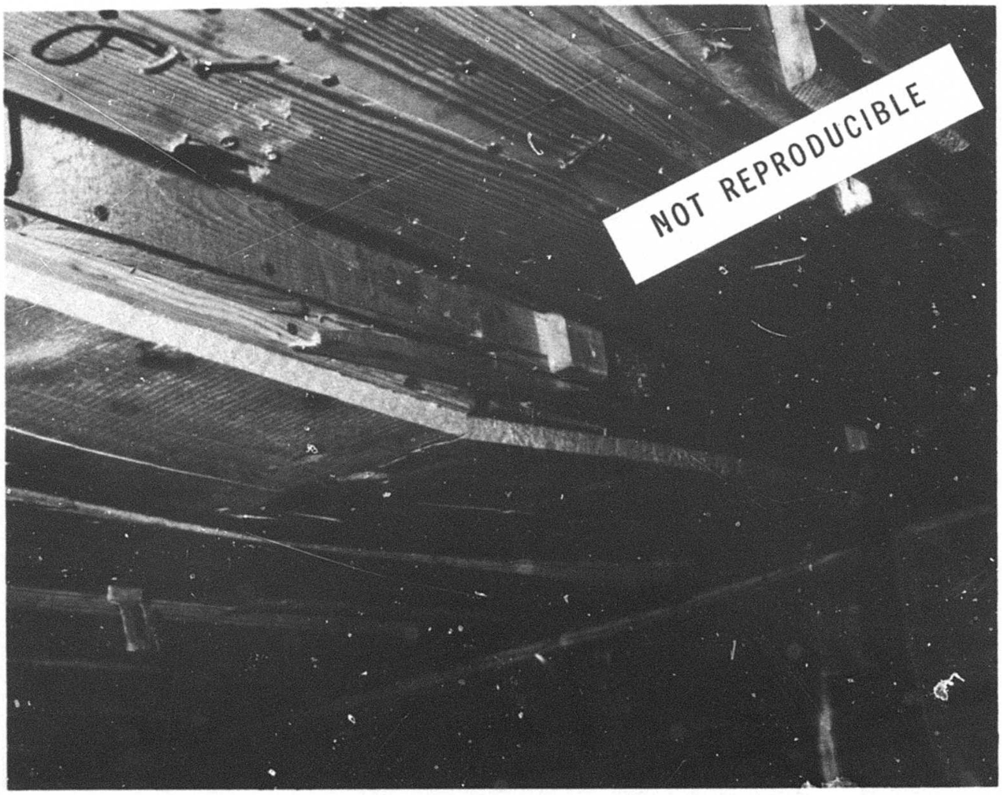


Figure F-10. Damage to roof beams from two 81-mm rounds.

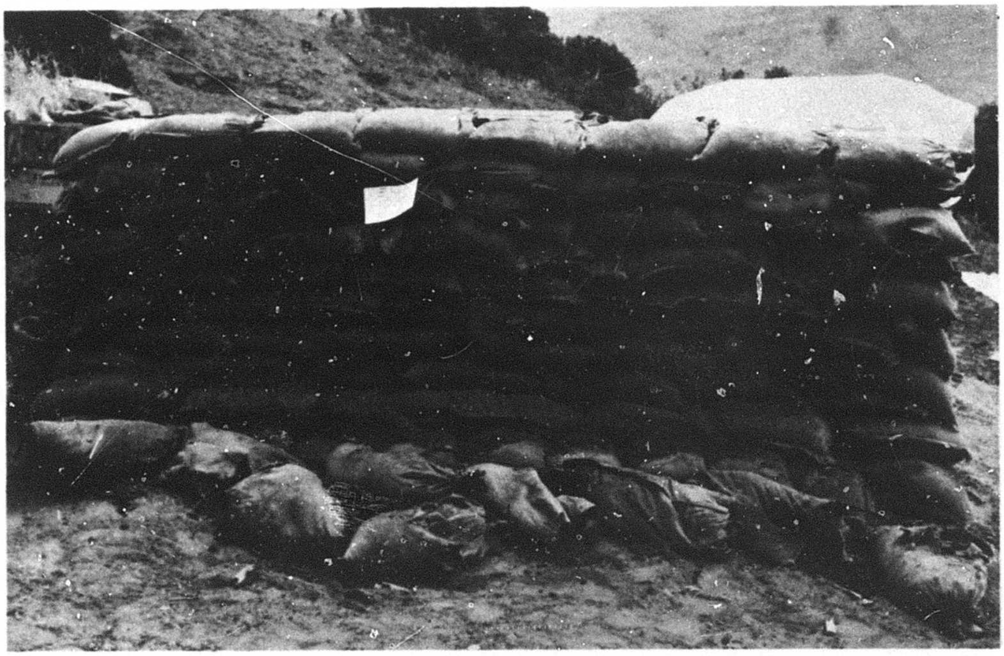


Figure F-11. Damage to sandbag wall from 81-mm mortar round at 10 feet.

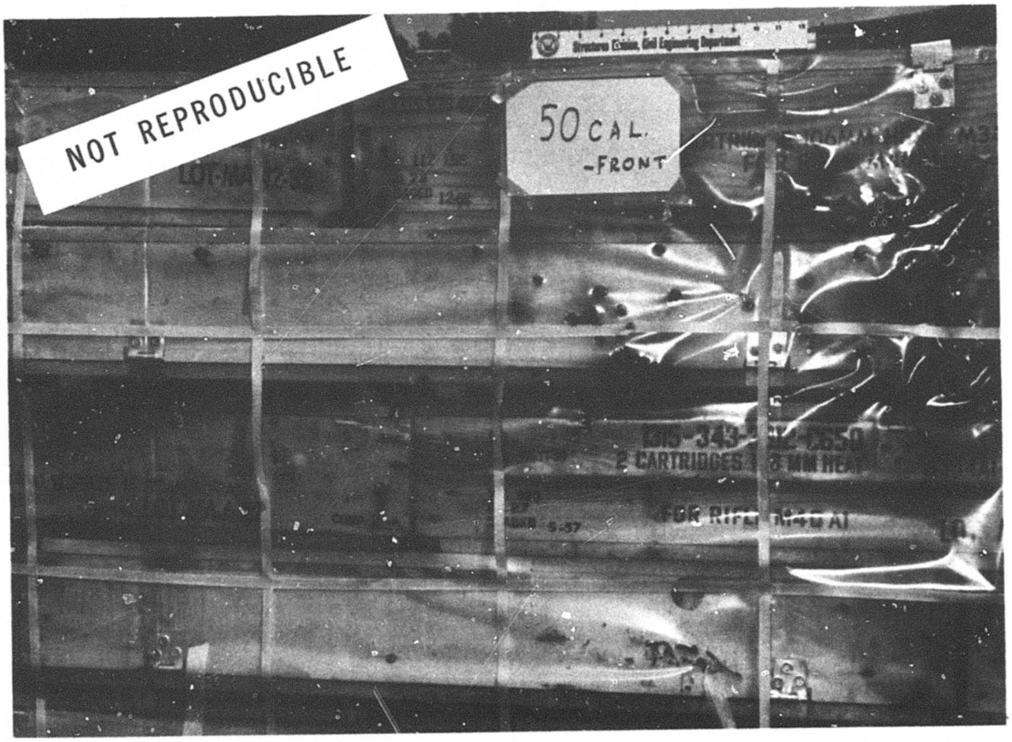


Figure F-12. Damage to test wall (front) from 50-caliber machine gun fire.

Figure F-13. Damage to test wall (rear) from 50-caliber machine gun fire.

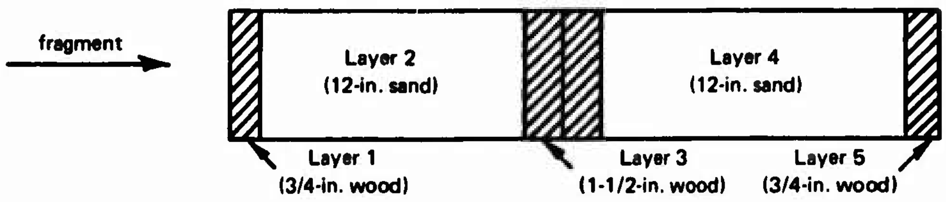
Therefore, in view of the large number of small particles, the presentation of test results in the form of an effectiveness percentage (number of fragments stopped per total number of hits) can be very misleading. To give the reader an indication of a realistic effectiveness of the ammunition boxes, the minimum size fragment considered will be 5 grains. (This is a conservative approach, since smaller particles are automatically stopped if a 5-grain fragment is stopped and if smaller particles were considered higher effectiveness ratings would result.) The effectiveness ratings of two soil-filled wooden ammunition boxes are

Weapon	Effectiveness
81-mm mortar	100%
105-mm artillery	98%
155-mm artillery	95%

On the basis of a modified form of the Poncelet equation and using the predicted heaviest mass fragment from the beam-spray of a 155-mm artillery round, two soil-filled ammunition boxes could stop that fragment and no penetrations would be expected (Table F-2). Observation of the fragments recovered at the test site indicates that fragments larger than the largest size predicted were produced. Based on the Poncelet equation, the heaviest mass 155-mm fragment that two sand-filled boxes can stop is 1,600 grains.

The Poncelet equation also shows that the penetration distance is very sensitive to the type of soil material used. A beach sand (Eglin sand) is about 2.5 times as effective as a sand–clay earthwork. The type of soil found at the test site was a sandy silt. A grain size distribution is shown in Figure F-14.

Table F-2. Theoretical Penetration Velocities



Cross Section of Two Ammunition Boxes

Location	Fragment Velocity (fps) of—	
	81-mm Mortar (37-grain fragment)	155-mm Artillery (1,535-grain fragment)
Initial striking	5,570	4,199
After Layer 1	5,083	4,088
After Layer 2	0[a]	837
After Layer 3	–	761
After Layer 4	–	150
After Layer 5	–	0[a]

[a] Fragment stopped within layer.

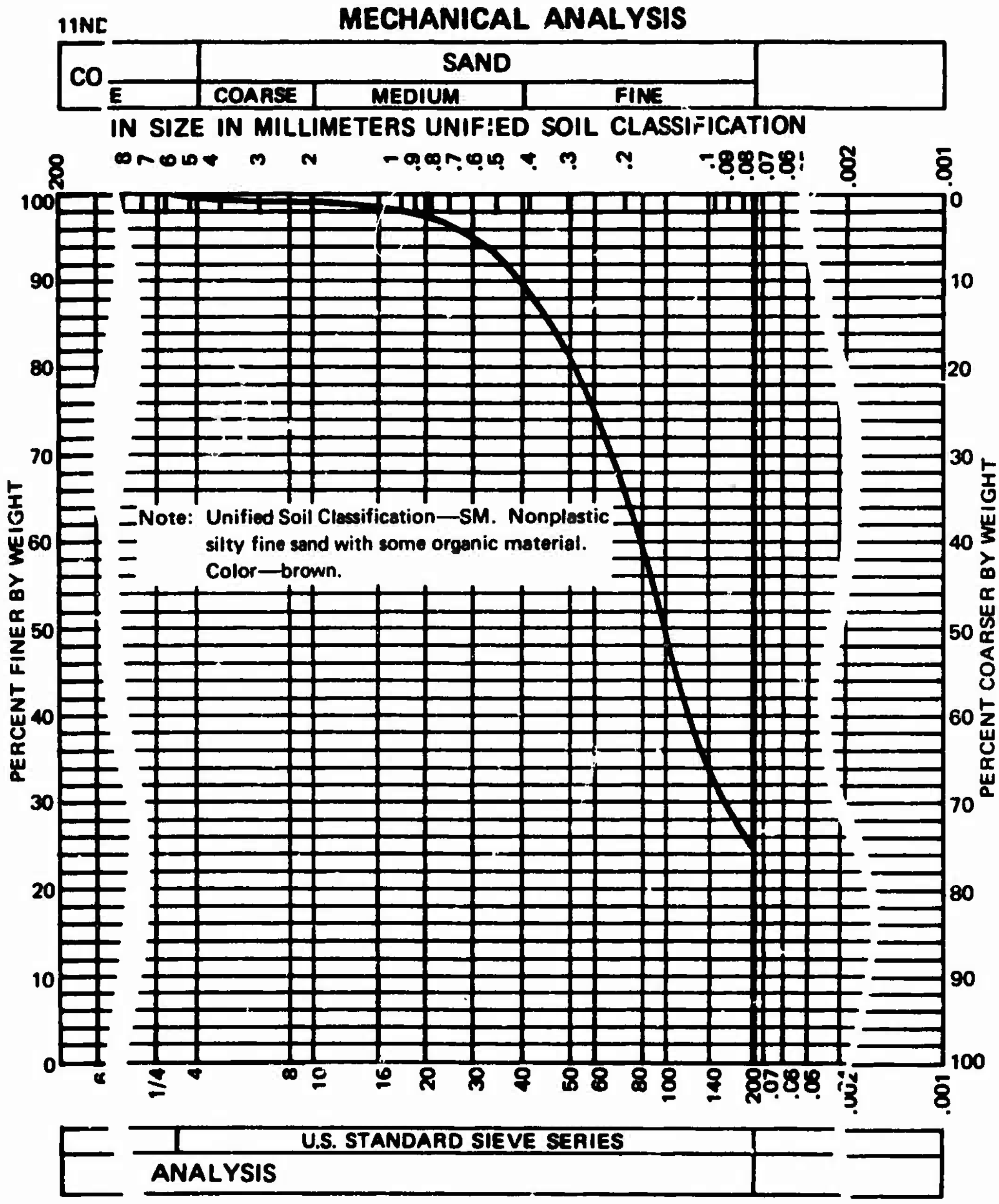


Figure F-14. Grain size distribution of soil.

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Naval Civil Engineering Laboratory
INVESTIGATION OF EMPTY WOODEN AMMUNITION BOXES FOR PROTECTIVE CONSTRUCTION (Final), by J. M. Ferritto
TR-738 70 p. illus October 1971 Unclassified

1. Tactical protective shelters 2. Bunkers and foxholes I. ZF 38.512.001.029

Empty ammunition boxes can serve as elements for construction of beams and bunkers to protect troops in the field. Various beam load tests have shown that it is possible to construct beams capable of safely carrying 2 feet of soil. Two specific designs are presented for beams which can span 7 and 10 feet carrying 2 feet of soil with a safety factor of 2. The problem of wood deterioration and loss of beam strength has been investigated and found not to be very significant. Beams placed side by side can serve as foxhole covers. Soil stability data are presented to determine minimum bearing areas required. Bunker construction plans have been developed and evaluated. Tests show the bunkers can be fabricated and will safely support the overhead load produced by 2 feet of soil protection. Blast and fragmentation tests indicate that the amount of protection given by a bunker is adequate against a 155-mm artillery round.

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